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Effect of Exhaust Gas Stirring on CH_4 Production in Batch Digester

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Abstract: **Sewage sludge is an undesirable organic matter, which is most frequently generated from the treatment process in wastewater treatment plants and causes environmental pollution if not well treated or used for energy generation. Sludge mostly contains biodegradable materials, which can produce methane as a generated biogas. Therefore, biogas production from sludge is a promising method of wastes treatment because it provides a good energy recovery as well as resolves environmental problems. In this study, secondary sludge and thickened sludge of a traditional activated sludge wastewater treatment plant were provided to determine the total solids content. The sludge types were digested for 30 days where generator exhaust was used for stirring for 15 minutes daily. Three experimental trials were conducted with a steel fixed dome, square-shaped anaerobic digester. Produced biogas was analyzed for the quantitative determination of methane (CH_4) and carbon dioxide (CO_2). The produced CH_4 was recorded to be zero, 60.7 % and 41.8 % when using secondary sludge, thickened sludge, and thickened sludge without stirring, respectively. Cumulative CH_4 production was studied for seven, 15 and 30 days. For thickened sludge, the results showed that approximately 80 % of produced CH_4 was between 15 and 21 days. A comparison between stirred digested thickened sludge and the digested thickened sludge without stirring was conducted and showed a good effect of the exhaust gas stirring. Increasing rate due to exhaust gas stirring was calculated and it was 31.14 %, 29.82 % and 20.39 % for 30, 15, 7 days, respectively.**

Keywords: **Anaerobic digestion, Batch digester, Methane production, Sludge, biomass, biogas.**

I. INTRODUCTION

Renewable and clean energy play an important role in the process of life and particular biomass could contribute in a significant way because it is a carbon nature fuel and could be considered a sustainable power source useful for environmental human use [1, 2]. It very well may be utilized for enthusiastic transformation through various processes, like biochemical or warm substance ones, contingent upon the biomass properties[2]. The anaerobic bacterial interactions have been generally utilized for sludge digestion absorption in wastewater treatment plants or for treating natural compost, accomplishing biogas to produce and deliver energy [3, 4].

A group of anaerobic microorganisms catalysis the process and transforms complicated macromolecules into low molecular weight chemicals, this process is called anaerobic digestion/decomposition [5, 6]. The anaerobic digestion process could be defined as a sequence of metabolic transformations induced by various bacterial consortia: Extracellular enzymes must first liquefy organic substrate materials such as cellulose, hemicellulose, and lignin [7, 8]. Then, organic materials are treated by acidogenic bacteria and soluble organic components including hydrolysis products are converted into organic acids, alcohols, hydrogen, and carbon dioxide by acidogenic [9]. The rate of hydrolysis depends on pH value, temperature, composition, and concentration of organic and intermediate compounds [10]. Acidogenesis products are transformed into acetic acid, hydrogen, and carbon dioxide [11]. Methane gas is created by methanogenic bacteria from acetic acid, hydrogen, and carbon dioxide, as well as additional substrates, the most important of which being formic acid and methanol [4, 8].

Stirring is the most important factor influencing anaerobic digestion's gas production rate [12]. The static digestion process has several drawbacks when there is no stirring, including uneven material distribution, poor fluidity, and difficulties with heat and mass transfer. Dynamic digestion, on the other hand, can successfully improve digestion efficiency and biogas production rate. Mechanical mixing, slurry recirculation, and produced gas recirculation are the three general mixing methods [13]. The benefits of mechanical mixing include high heat and mass transfer rates, as well as successful reduction of hydraulic dead space, reproduction, better dispersion of the substrate for contact with microorganisms, uniform substrate temperature, reduction of scum and deposits formation and metabolism of anaerobic bacteria. It has been reported that efficient mixing promotes methane production and the destruction of volatile solids (VS) [14].

There are two ideal temperature ranges for the performance of anaerobic bacteria: one at 20 – 40 °C for mesophilic microorganisms and one at 45 – 60 °C for thermophilic microorganisms. The operation of a digester in the mesophilic range is more stable, as these microbial communities can tolerate greater changes in environmental parameters and consume less energy [15]. Not only temperature is important for anaerobic digestion, but also large temperature variations, such as those between day and night or seasonal variations, can also hurt the performance of anaerobic digestion [2].

This paper focuses on the digestion process by fixed dome digester using sewage sludge and applying a new technique of stirring. The research scope was to investigate methane gas production from two sludge types and study the effect of exhaust gases stirring on batch digester to produce methane gas.

II. MATERIALS AND METHODS

Digestion processes depend on a multitude of variable interrelated factors such as temperature, organic matter content, pH-value, alkalinity, nature of biomass, stirring, C/N ratio and Experiment duration [2, 14]. Due to the diverse ability of the factors, it is a common practice to identify certain ones to focus on. The experimental trials were focused on the effect of stirring, solids content for various types of used sludge.

A. Pilot Setup

A laboratory pilot scale digester was built up using steel sheets with a filling and feeding system on the top cover and under the drainage system. The digester is a rectangular tank constructed of steel with an internal cavity for the substrate and a surrounding compartment that serves as a jacket and works as stiffeners. The substrate capacity (internal zoon) for the digester is approximately 160-liter volume with the inner dimensions of 0.4 * 0.4 m with 1 m clear height. The outer dimensions, encompassing the stiffener rooms, are approximately 1.5 m^3 volume with dimensions of 1 * 1 m and 1.5 m height, including unloading hopper cone. A six mm fixed steel cover with 3 top openings was used, the first one is for pressure gauge, the second one is for filling and the third one is for exhaust gas entrance. The digester cover is attached with an internal perforated 0.5-inch pipe started from the bottom of the internal tank to make sure the mixing gas is passed through all the sludge volume. The digester was designed to hold the produced gases on it and the final outlet for gases is at the top of the tank. Fig. 1 shows a schematic diagram of the experimental set-up for the anaerobic digester. Fig. 2 shows a photo of the experimental pilot setup with all components.

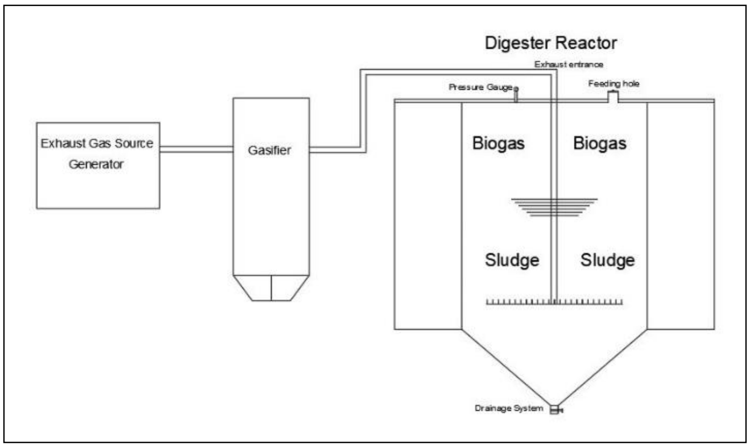

Fig. 1: Schematic diagram of the experimental setup for the anaerobic digester

Fig. 2: Photo of the experimental pilot setup with all components

B. Materials

Two different biomasses (secondary sludge and thickened sludge) were digested in the single-stage, batch scale mesophilic anaerobic steel digester at the Biofuel Laboratory - El Mattria faculty of engineering - Helwan University. Sludge samples were collected from El-Berka WWTP at Madinat El Salam district in Cairo, Egypt. TABLE 1 shows average characteristics values for the collected thickened and secondary sludge samples. Three experimental batches were carried out by using generator exhaust gasses for stirring, the last batch was with thickened sludge but without stirring to study the effect of stirring on CH_4 production. Experimental trials were carried out to investigate methane gas production with mixing by generator exhaust for 15 minutes for consecutive 30 days.

TABLE 1: SLUDGE AVERAGE CHARACTERISTICS DATA

No.	Parameter	For Thickened Sludge	For Secondary Sludge
1	pH	6.17	6.22
2	TS, %	1.87	N/A
3	TVS, %	1.37	N/A
4	TS, mg/l	19183	4287
5	Temperature, ^{o}C	20	18

TABLE 2: EXHAUST GAS COMPONENTS

No.	Compound Name	Amount Molar %
1	CO_2	86.08
2	Propane	1.78
3	i-Butane	6.52
4	n-Butane	4.88
5	i-Pentane	0.55
6	n-Pentane	0.19

New stirring technique was applied by the exhaust gas emitted from a lab-scale generator used as a source of exhaust that was used for mixing in the digester. The mixing process was done daily for 15 min and the operating range of the temperature was from 25 to 35 ^{o}C depending on the initial start degree and the seasonal degrees. The hot exhaust gas led to an increase in the sludge temperature by 1 or 2 degrees, but the temperature was still in the mesophilic range. TABLE 2 shows exhaust gas components. The main gas in the exhaust was CO_2 and other hydrocarbons.

C. Measurements and Error analysis

In this experimental series, parameters were measured such as initial temperature, initial and final pH, and biogas production. The temperature was measured by thermocouple K-Type. The initial and final pH value was measured by pH 340i (WTW). Gases ratio was conducted in Cairo Oil Refining Company (Chemical and Research Department) according to standard methods. TABLE 3 shows the specification of the instruments used for measurements.

Experimental error analysis is the difference between a measurement and the true value or between two measured values. The purpose of the error analysis is to determine the most important errors that affect the final result. Error analysis could be defined as a ratio between the minimum digit of the instrument and the minimum reading in the experiment. TABLE 3 shows the experimental error in the four used instruments.

TABLE 3: SPECIFICATION OF USED INSTRUMENTS

Parameter	Instrument	Error
Temperature	Type K, CG-96BD	± 0.04 ^oC
pH	pH 340i (WTW)	± 0.01
Gas Detector	G750 Polytector II (GFG)	± 2.5 % Vol.
Gas analyzer	7890B GC System	± 1% Vol.

III. RESULTS AND DISCUSSION

A. CH_4 Production

To investigate the biogas production using different types of sludge as biomasses, three batch digesting experiments were conducted with secondary sludge, thickened sludge and thickened sludge without gas stirring. Fig.3 shows the responding generated gases from the digested biomasses. Different types of produced gases were tested by ratios such as Methane (CH_4), Carbon dioxide (CO_2), Nitrogen (N_2), i-Butane, n-Butane, n-Pentane, Propane, Ethane and Hexane. The main produced gases were Methane (CH_4) and Carbon dioxide (CO_2) with high ratios but also contains several other gaseous “impurities” such as Nitrogen (N_2), Propane, and Hexane.

Methane and Carbon dioxide could be considered the main active production for the digestion process [2]. Both of the two produced gases have one carbon atom in their chemical formation. Because of the huge amount of carbon in the used biomasses. TABLE 4 shows Methane and Carbon dioxide ratios and other gases ratios produced with different types of biomasses in the three experiments.

TABLE 4: RESULTS FOR BIOGAS COMPONENTS PRODUCTION FROM DIFFERENT BIOMASSES

No.	Biomass Type	CH_4	CO_2	N_2	i-Butane	n-Butane	n-Pentane	Propane	Hexane
1	Secondary sludge, %Vol	0	93.6	3.6	1.3	1	0.5	0	0
2	Thickened sludge, %Vol	60.7	39.1	0.2	0	0	0	0	0
3	Thickened sludge without stirring, %Vol	41.8	0	0	11.1	9.8	0	35.7	1.6

Methane production rate at a specific condition was defined as the methanogenic activity under these conditions. During the start-up period, Methane production rate and time were able to represent two useful operational indicators for monitoring the acclimation condition of methanogens with one specific substrate in an anaerobic digester. Two different cases of effect should be considered: the initial shock loading effect when the bacteria were acclimatized, and the steady case that occurred for the well-acclimatized bacteria for the rest of the time [16]. Throughout the batch digestion period (approximately 30 days), the cumulative biogas production increased at a fast rate. However, the first fifteen days produced about half of the total methane released in batch digestion. From day 7 to the end of the batch operation, methane concentrations were reported in the 20-60 % range. As a result, this finding exposed that biogas production had increased significantly. It could be observed that two batches gave satisfying results in the first 15 days for the thickened sludge alone and the thickened sludge without stirring. TABLE 5 shows the methane gas production rate for different biomasses in 7, 15 and 30 days.

Fig. 4 shows the cumulative methane production for the different experimental techniques. From Fig. 4 and Fig. 5, It could be noticed that the main increasing interval is from 7 to 15 days, which mean the digestion time could be decreased to 15 or 21 days because approximately 83 % of the produced CH_4 was achieved in the first 15 or 21 days approximately.

TABLE 5: METHANE PRODUCTION RATES FOR DIFFERENT BIOMASSES IN 7, 15 AND 30 DAYS

No.	Biomass Type	After 7 days CH_4 %	After 15 days CH_4 %	After 30 days CH_4 %
1	Secondary sludge	0	0	0
2	Thickened sludge alone	15.2	50.3	60.7
3	Thickened sludge without stirring	12.1	35.3	41.8

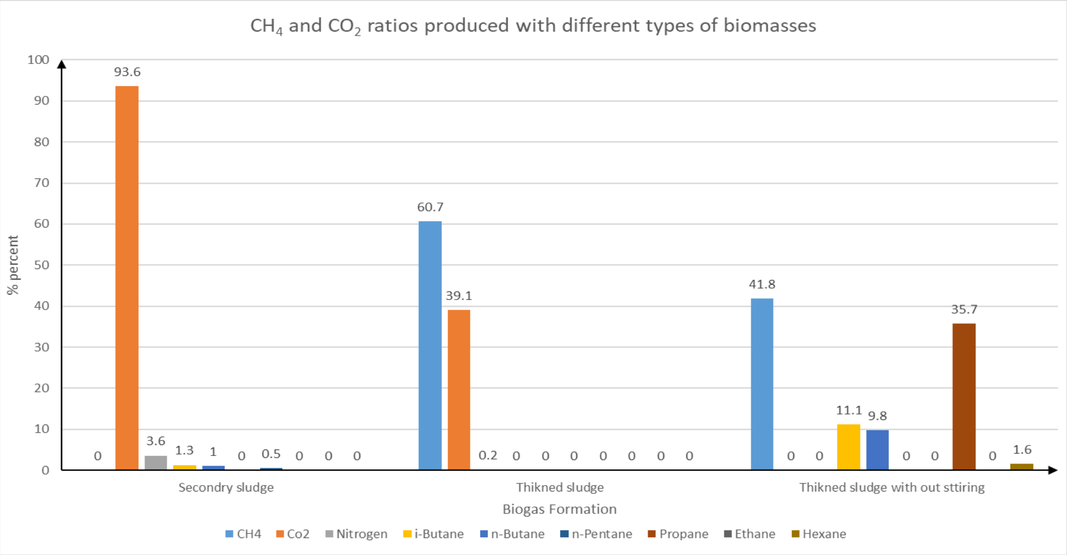

Fig. 3: Responding produced gases from the digested biomasses

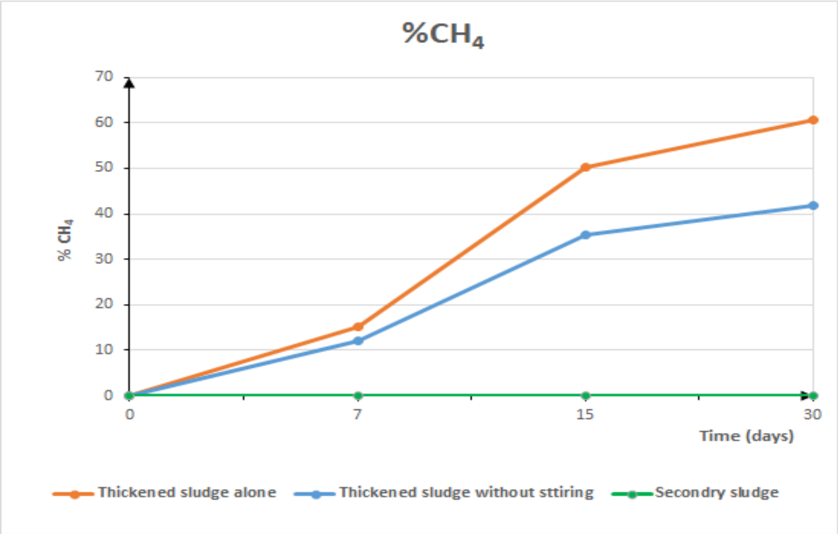

Fig. 4: Cumulative methane production for the different experiments

B. Effect of stirring

Mixing and stirring is a vital factor for achieving uniformity among the substrate concentration, temperature, and environmental conditions to reduce the chance of scum formation and solid deposition [15]. To understand the effect of stirring on methane gas production, the increasing rate in methane gas was calculated between the thickened sludge alone and the thickened sludge without stirring. Equation 1 for the increasing rate was applied at 7,15, 30 days to calculate the rate of increase due to the stirring. The percent increasing rates were 31.14 %, 29.82 % and 20.39 % for 30,15,7 days, respectively. Fig. 5 shows the increasing ratios due to stirring between the different times.

$$\%\text{Increasing Rate} = \frac{\%CH_4\text{with stirring} - \%CH_4\text{without stirring}}{\%CH_4\text{with stirring}} * 100 \quad \text{………. Equation 1}$$

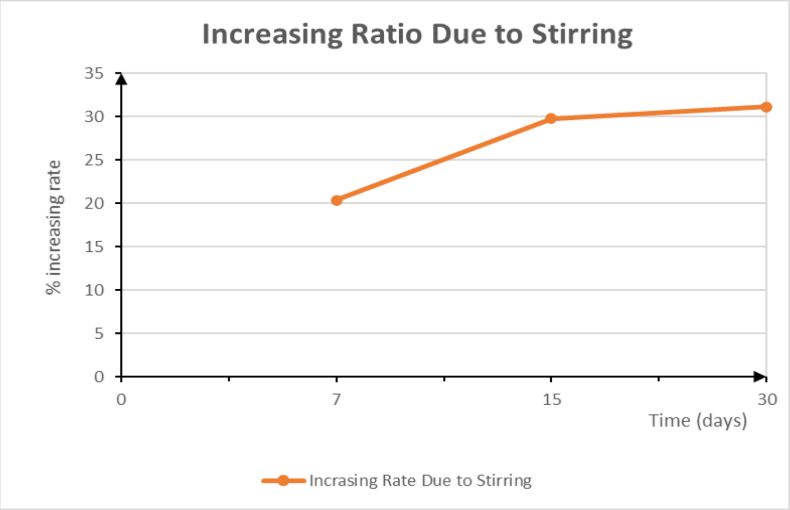

Fig. 5: Increasing ratio due to Stirring

C. Effect of organic loading and temperature

Organic loading and temperature are two main factors in anaerobic digestion and also these experimental trials. Organic loading represented in the total solids (mg/l) of the thickened and secondary sludge [17]. Total solids of the thickened sludge were larger than in secondary sludge, which lead to the high efficiency of thickened sludge more than secondary sludge in CH_4 production. Secondary sludge did not give any methane production due to less organic loading (TS=4287 mg/l); the main produced gas was CO_2 in this experimental trial. Thickened sludge achieved 60.7 % and 41.8 % when stirred and non-stirred, respectively. These results were a result of the digestion of a large organic load in the thickened sludge (TS=19183 mg/l). The temperature of the digested sludge was ranged from 25–35 °C via the hot exhaust gas that enters the digester reactor, which means the digestion process was in the mesophilic range. Temperature significantly affected the methane production rate because temperature encourages mesophilic bacteria to produce methane gas from anaerobic digestion. Due to that several studies mentioned that the methane production rate highly increased for every increase in temperature [18].

IV. CONCLUSIONS

Biogas produced from anaerobic digestion is considered a sustainable renewable energy source. This paper shows that anaerobic digestion in pilot-scale bioreactor digester stirred by generator exhaust proved successful continuous operation for biogas production. Secondary and thickened sludge from traditional activated sludge WWTP was used in three experimental trials with and without stirring by exhaust gas. Methane production percent in biogas produced from the anaerobic digestion process was recorded to be zero, 60.7 % and 41.8 % for secondary sludge, thickened sludge, and thickened sludge without stirring respectively. Cumulative methane production through thirty days was studied and stirred thickened sludge gave acceptable positive results, however secondary sludge did not give and produced methane due to the low organic load in the sludge. Stirring is highly recommended for the digestion process because its rapid bacterial reaction makes a suitable environment for anaerobic bacterial growth and increase the methane production rate. Stirring, organic load and temperature are affecting factors for biogas production rate.

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