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Treatment of Activated Sludge by Microorganism for Biogas Production

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Anaerobic digestion; Sewage sludge; Methane content; Hydraulic retention time (HRT).

Abstract The treatment of sewage sludge by anaerobic digestion is considered the best way for disposal of pathogenic organisms and limiting of infectious diseases. Another benefit is the production of compost used safely as agricultural fertilizer. Not only that but also production of biogas. In the present study, biogas is produced from sludge, cattle dung and a mixture of them 50:50 % volume, by batch vertical anaerobic digester under 36 °C mesophilic conditions. The feasibility shown that, the expected quantity of biogas per day according our experiments from Dakahliya and Mansoura is 17271 and 7098.4 m^3/ day, respectively. According to available data, the total estimated biogas potential in Egypt is 480850.6 m^3/ day. The optimum range of pH was 7.1 for production of biogas with 59.6 %, 70.6 and %, 66.7 % methane for the sludge, the dung and the mixture, respectively. The quantity of biogas produced from sludge and mixture was higher and longer HRT than dung.

1. Introduction

Nowadays there is a worldwide increasing energy demand. Biogas is an ideal fuel to meet rural residential energy demand (especially, cooking, lighting and heating). It is clean-burning, thereby causing little or no indoor pollution during combustion, and is a locally available renewable source.

This study focuses upon the case of Egypt, where a highly productive sludge from wastewater treatment plants (WWTPs) can be utilized for increasing energy demand. The sludge produced from municipal wastewater treatment plants seems to be a problem in Some countries, while in other countries it is recognized as an environment- friendly source of power rather than being a burden on the environment. For a long period, Egypt has been concentrating its efforts on sanitation services mainly on wastewater treatment, while little priority has been given to sludge management in practice (Ghazy et al., 2009). The total number of WWTPs in Egypt is 303 and they treat from $10.0x10^6$ to $11.85x10^6$ m^3/ day of wastewater. The methods and technologies for sewage sludge treatment implemented in Egypt were very limited. The main attention was devoted to the process of sludge drying, mainly through natural drying beds without any interest in the characteristics or the quality of the produced sludge.

Recently, there is increasing interest in expanding the use of new techniques and methods for sewage sludge treatment. The use of anaerobic digestion technology is an ideal cost-effective biological method to produce biogas from wastewater and to meet our country targets. It is the appropriate choice for Egypt. Warm weather helps reduce the daily accumulated sludge from sanitation WWTPs. Our results and feasibility study show that the estimated daily production of biogas in Dakahliya WWTPs is 17271 m^3/ day and in Mansoura WWTP is 7098.4 m^3/ day.

In many countries, sewage sludge is a serious problem due to its high treatment costs, and the risks to environment and human health. Although, the volume of the produced sewage sludge represents only 1 - 2 % of the treated wastewater volume, its management costs are usually ranging from 20 – 60 % of the total operating costs of the wastewater treatment plant (Marcos and Chernicharo, 2005).

The important processes in anaerobic digestion are hydrolysis, fermentation, acetogenesis, and methanogenesis. In the hydrolysis stage, complex organic materials are broken down into their constituent at parts such as amino acids, fatty acids, simple sugars and glucose (United Tech., 2003).

Anaerobic digestion is used to stabilize the sewage sludge and to convert part of the organic total solid (OTS) compounds into biogas. The biogas can be applied as an energy resource either at the wastewater treatment plant itself or elsewhere. In comparison to mesophilic digestion, thermophilic treatment has some advantages, such as a somewhat higher biogas production, a higher destruction degree of pathogens, and a larger reduction in the amount of organic solids. The retention time of the sludge in the reactor can be also reduced (Rulkens, 2008). Biogas is generated when bacteria degrades biological material in the absence of oxygen (anaerobic digestion). The main constituents of biogas are CH_4 and CO_2 gas. It usually contains about 50 - 70 % CH_4, 30 - 40 % CO_2, and other types of gases, including ammonia, hydrogen sulfide and other gases. It is also saturated with water vapor (Eshraideh, 2002). The biogas burns very well when the CH_4 content is more than 50 %. Therefore, biogas is a renewable fuel produced from waste treatment and can be used as a substitute for kerosene, charcoal, and firewood for cooking, heating, lighting or even absorption of refrigeration (World Energy Council, 1994; Al Sadi, 2010). It is also used to run pumps and equipment of gas–powered engines rather than using electricity.

Anaerobic digestion is a complex microbial process wherein, a variety of bacteria is involved. These bacteria can be broadly classified as fermentative, acetogenic and methanogenic bacteria (Mclnerney and Bryant 1981). Hydrolytic bacteria bring about initial degradation of complex biopolymers such as cellulose, hemicellulose, proteins and lipids into dicarboxylic acids, volatile fatty acids (VFA), ammonia, carbon dioxide, hydrogen, etc. Methanogenic bacteria which plays a key role in the terminal step of anaerobic digestion use only a few compounds like acetate, methanol, methylamine, hydrogen and carbon dioxide (Meher and Ranade, 1992).

The objectives of the present work are to characterize the anaerobic biodegradability potential of sewage sludge with cattle dung using batch experiments vertical digesters under mesophilic temperature, to determine the most suitable conditions for biogas and methane production, and to utilize many wastewater plants present in Egypt to solve fuel and energy problem.

2. Materials and Methods

Experiment 1: Sewage Sludge Substrate:

The sewage sludge used for the experiment was collected from Mansoura Wastewater Treatment Plant (WWTP) in Egypt. The pH of sludge was 5.4 at the beginning, 5.7 % TS and 4.42 % OTS.

Experiment 2: Cattle Dung Substrate:

Cattle dung was collected from animal shed in rural village near to Mansoura city and was prepared before put into the fermentor. The starting pH for dung was 7.1, 6.8 % TS (diluted from 11.8 % TS) and 5.1 % OTS.

Experiment 3: Mixture Substrates:

The substrates are mixture of sewage sludge and cattle dung 50:50 % volume. The same ratio was previously recommended (Abdel-Hadi, 2009). The starting pH for mixture was 6.4, the mixture TS was 8 % (11.8 % TS for dung and 4.3 % TS for sludge) and OTS was 6.14 % as shown in the mixture sample which was collected before putting into the digester. The characteristics of the sewage sludge, the cattle dung and the mixture are shown in Table 1.

Table 1: The characteristics of sewage sludge, cattle dung and mixture.

Characteristic	Sludge	Cattle dung	Mixture
pH	5.4	7.1	6.4
Total solids, TS (g/L)	57.0	118.0	80.0
Organic total solids, OTS (g/L)	44.2	88.5	61.4
OTS (% of TS)	77.54	75.0	76.75
Organic carbon (% of TS)	44.98	43.5	44.52
Carbon: nitrogen ratio C:N	9:1	24:1	13:1
Alkalinity (mg/L) as $CaCO_3$	4,800	5,900	5,500

2.1 Bench-Scale Biogas Digester:

A bench-scale of cylindrical biogas digester (vertical type) was constructed at the workshop in Mansoura WWTP. The digester was fabricated from galvanized steel sheet of 270 mm long, 200 mm diameter with total capacity of 8.5 liters, actual digestion volume of 6 liters and stirrer 80 rpm/min. under 36 °C mesophilic conditions. To monitor the digestion processes, the digester was equipped with two orifices; one for releasing the produced gas and the other for measuring the pH and the temperature. Released gas volume was collected in gasholder and determined as shown in Fig. 1.

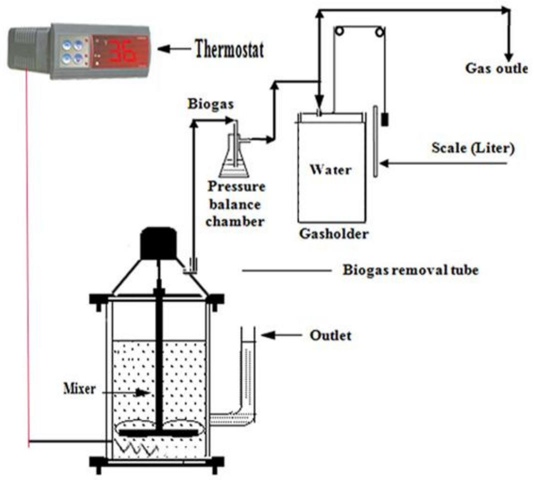

Fig. 1. Schematic diagram of vertical bench-scale biogas digester.

2.2 Analytical Methods and Instrumentation:

Total solids (TS) and organic total solids (OTS) were calculated based on the (APHA-AWWA-WPCF, 1998) and (DEV, 1971) formula.

Meanwhile, the OTS mass in kg was determined from (Wittmaier, 2003).

Organic total carbon (OTC): can be calculated according to (Black et al., 1965).

Daily biogas production: During the batch fermentations, the released gas volume was measured in liter everyday in our laboratory using the wetted displacement with a previously calibrated scale.

Methane percentage: The daily released biogas was fractioned in a percentage i.e. methane and CO_2 percentage. Methane content was measured by absorption of carbon dioxide with 40% of KOH (Okeke and Ezekoye, 2006; Abdel-Hadi, 2008).

Temperature and pH: Temperature and pH value of the mixture solution inside the bench-scale digesters were daily measured on a regular basis using Symphony pH meter.

Degradation ratio: The degradation ratio of organic matter was determined every 5 days over the hydraulic retention time (HRT) for each experiment. It was determined as the percentage of the difference between the OTS from the beginning of the experiments and after definite number of days divided by the OTS at the beginning.

3. Results and Discussion

3.1 Effect of pH Change at Different Intervals for Three Experiments

Daily monitoring of pH shows that the best production of biogas occurs at pH 7.1 for the sludge, the dung and the mixture. This agrees with the results of (Moosbrugger et al., 1992), that the optimum pH range for anaerobic digesters is from 6.6 to 7.4. The measured pH values for anaerobic digestion of sludge, cattle dung and mixture at experimental intervals are shown in Fig. 2. The pH for sludge started from 5.4 and then increased up to 7.5, for cattle dung started from 7.1, decreased to 5.9 and raised again to 7.1, while in the case of mixture the pH started from 6.4, decreased to 6.1 and raised again to 7.1.

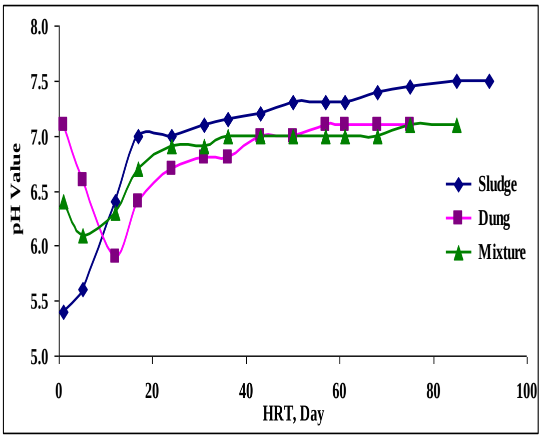

Fig. 2. Change in pH values for sludge, dung and mixture.

The pH is known to influence enzymatic activity because each enzyme has a maximum activity within a specific and a narrow pH range. The pH of the digestion liquid material and its stability as well comprise an extremely important parameter. Since, methanogenesis only proceeds at high rate when pH is maintained in the neutral range as indicated in (Abdel-Hadi and Abd El-Azeem, 2008).

Most methanogenic bacteria function optimally at pH 7.0 to 7.2, and the rate of methane production declines at pH values below 6.3 or exceeding 7.8 (Bitton, 1994; Van Haandel and Lettinga, 1994).

3.2 Biogas and Methane Production:

Biogas, methane yield and percentage were recorded in three experiments with mesophilic conditions. Fig. 3 shows the production of biogas from the three experiments of sludge, cattle dung and a mixture of them, respectively, along with the hydraulic retention time (HRT). The calculation of biogas quantity in case of dung was 197.4 L kg^{-1} OTS, and methane yield was 132.5 L kg^{-1} OTS with methane quality percentage 70.6 %. In the sludge experiment, biogas quantity was 261.5 L kg^{-1} OTS more than dung with long hydraulic retention time. The results show that the biogas yield in the third experiment for the mixture was 235 L kg^{-1} OTS, and methane yield was 156.3 L kg^{-1} OTS. Determination of methane quality and percentage was 66.7 %.

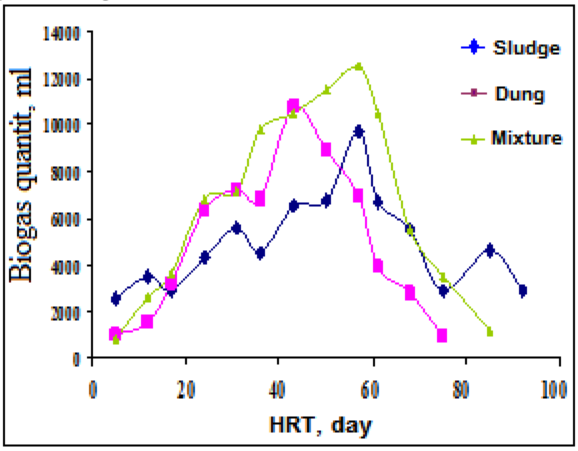

Fig. 3. The comparison of results among the sludge, dung and mixture biogas quantities and HRT/ day.

Methane yield from sludge was 153 L kg^{-1} OTS, and less in quality of methane 59.7 % which is illustrated by the comparison between methane quantities and percentage of quality for methane as shown in Fig. 4. The methane percentage expressed in Fig. 4 shows clearly that the cattle dung has high quality of methane 70 %, the mixture quality was 67 %, and sludge quality was 60 %. It was expected that the decreasing in sludge quality was more than in the cattle dung, and this may be due to the higher biomass of the cattle dung than in sludge or to the presence of other contaminations that affect methanogenic bacteria as detergents and chemicals from domestic wastewater.

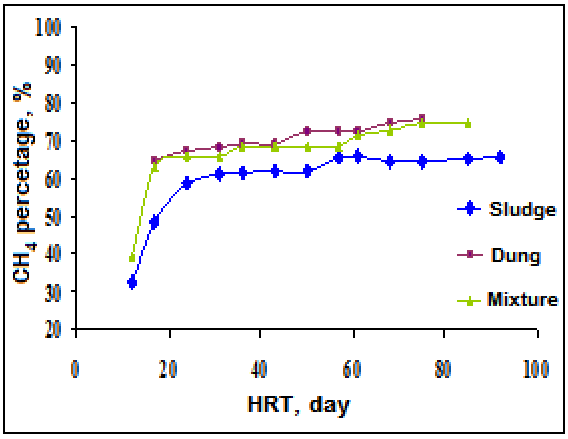

Fig. 4. CH_4 percentage and its quality for sludge, dung and mixture with HRT/ day.

3.3 Degradation of Organic Carbon

The decomposition of sludge and cattle dung under anaerobic digestion has a high response towards other parameters present, for example the concentration of organic total solids (OTS) and the degradation rate. The degradation ratio of organic matter was determined each five days along with the hydraulic retention time (HRT) for the three experiments as indicated in Fig. 5. This agrees with (Abdel-Hadi and Abd El-Azeem, 2008).

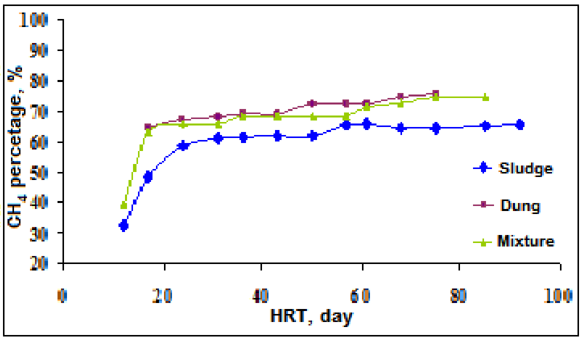

Fig. 5. Degradation of organic carbon for sludge, dung and mixture.

4. Conclusions

The present work illustrates the technical and economic viability of producing methane (CH_4) from wastewater treatment. The stability and constancy of the production of biogas depends on the existing sludge, cattle dung and mixture of them. This study can be applied in many wastewater plants present in Egypt and elsewhere to solve fuel and energy problems without need to further technological adaptation.

Egypt's warm weather is in favor of the use of anaerobic digestion. The highest biogas production from sludge or mixture observed was positively correlated with pH. Adjusting pH has great effect on methanogenic bacteria activity and methane production.

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معالجة الحمأة النشطة بواسطة الكائنات الدقيقة لإنتاج الغاز الحيوي (البيوجاس)

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تعتبر معالجة الحمأة النشطة بالتخمر اللاهوائي هي أفضل الطرق للتخلص من البكتيريا الممرضة والكائنات المتطفلة، والحد من انتشار الأمراض المعدية، بالإضافة لإنتاج سماد يستخدم بصورة آمنة كمخصب للمحاصيل الزراعية. ليس هذا فقط ولكن أيضا إنتاج الغاز الحيوي (البيوجاس). إجراء هذه التقنية في مصر محدود بالرغم من أنها تستطيع تحويل المخلفات العضوية لغاز حيوي لإنتاج الطاقة لتحقيق فوائد بيئية واقتصادية.

الهدف من الدراسة: هو تحري الظروف المناسبة التي تؤثر علي إنتاج الغاز الحيوي ومدى جودته واستغلال كثير من محطات مياه الصرف الموجودة في مصر لحل مشكلة الوقود والطاقة.

الادوات والطرق المستخدمة: أجريت دراسة معملية علي خليط من حمأة الصرف الصحي وروث الأبقار في مخمر رأسي وكذلك تجربة للحمأة علي حدة وللروث علي حدي ونسب الخلط ٥٠ : ٥٠ ٪. تم إجراء التجارب عند درجة حرارة ٣٦°م بالنظام الميزوفيلي ومتابعتها يوميا.

النتائج: المادة الجافة الكلية لحمأة الصرف الصحي، وروث الأبقار، والخليط هي ٥.٧ ٪ ، ٦.٨ ٪ ، ٨ ٪ علي التوالي. وكانت كمية الغاز الحيوي في حمأة مياه الصرف أكبر من كميته من روث الأبقار، ولكنها استغرقت وقتا أطول للتخمر، وكانت كفاءة الإنتاج في الروث أعلي من الحمأة. تم تقدير النسبة المئوية للمادة الجافة العضوية OTS معملياً للمواد المتخمرة وحساب نسبة التحلل خلال وقت الاستبقاء. تم حساب كمية الغاز الحيوي والميثان باللتر فكان إنتاج الغاز الحيوي الكلي في حال الحمأة ٢٦١.٥ لتر/كجم من المادة العضوية وهو بذلك أكبر من الروث الذي كان ١٩٧.٤ لتر/كجم من المادة العضوية لفترة تخمر أقل من الحمأة. تم عمل دراسة جدوي لكمية البيوجاس علي محطات محافظة الدقهلية مجمعة والمنصورة علي حدة، ومحطات مصر مجمعة فكان المتوقع إجمالي الغاز الناتج يومياً علي الترتيب: ١٧٢٧١ م^{3}/يوم، ٧٠٩٨.٤ م^{3}/يوم، ٤٨٠٨٥٠.٥٥ م^{3}/يوم مما يحقق عائدا اقتصاديا كبيراً فضلاً عن إنتاج سماد غني بالعناصر اللازمة لتغذية ونمو النبات بصورة آمنة.