POTENTIAL OF BIOGAS PRODUCTION FROM ACTIVATED SLUDGE AND ENERGY RECOVERY FOR WASTEWATER TREATMENT PLANTS

Abdel-Hadi, M. A.*

ABSTRACT

The application of anaerobic digestion process with energy recovery is a promising option for sewage sludge stabilization in Egypt, which estimated around 2 million tons/year of dry sewage sludge from wastewater treatment plants (WWTPs). The paper presents an example of energy recovery of reuse sewage sludge according to operating data from the Serabium wastewater treatment plant, Ismailia, Egypt. Therefore, the objective of the present study was to investigate the possibility of biogas and methane production by mono-digestion sewage sludge, cattle dung and co-digestion mixture of them 1:1% volume in three vertical digesters batch bench-scale under mesophilic bacteria region 36 ^{o}C and 92 days hydraulic retention time (HRT). The results showed that, the substrate specific biogas production values were 0.177, 0.153 and 0.183 $m^3\,kg^{-1}$ TS, while the average degradation percentages were 21.8, 28.4 and 26.2% proportional with the average methane percentages of 57.3, 63.5 and 62.6% for sewage sludge, cattle dung and mixture, respectively. The Chemical oxygen demand values (COD) were decreased from 46.0, 61.3 and 56.3 g L^{-1} at the beginning of experiment to 34.7, 41.2 and 39.0 g L^{-1} at the end of experiment for sewage sludge, cattle dung and mixture, respectively. The biogas energy and electrical energy which can be produced from sewage sludge from one cubic meter treated wastewater were 0.226 kWh and 0.079 kWh_{el}, respectively. Production of electrical energy from biogas conducted in Serabium wastewater treatment plant leads to coverage approximately 23.4% of the total demand energy, which the average energy consumption was 0.337 kWh/m^3 wastewater.

Keywords: Biogas, Sewage sludge, Wastewater treatment plants, Energy recovery, Electrical energy

---

***Associate Prof. department of Agricultural Engineering, Faculty of Agriculture, Suez Canal University, 41522 Ismailia, Egypt.**

1. INTRODUCTION

In many countries, sewage sludge from wastewater treatment plants (WWTPs) is a serious problem due to its high treatment costs, energy consumed and the risks to environment and human health. The amount of sewage sludge produced in Egypt from WWTPs was estimated around 2 million tons/year of dry sludge in 2008 **(Ghazy et al., 2009)**. It has been, therefore, necessary to develop strategies for efficiently management of the generated sludge. Anaerobic digestion (AD) is the most common treatment technique for sludge stabilization resulting in a reduction in the amount of volatile solids (VS) with biogas production at the same time as a renewable energy source which could recover 20-40% of the electrical energy requirement of the plant **(Dereix et al., 2006; Crawford and Sandino, 2010).** In order to improve the performances of anaerobic digesters, the co-digestion of waste activated sludge together with other organic wastes such as cattle dung manure is a common practice adopted in wastewater treatment plants **(Bolzonella et al., 2006 and Davidsson et al., 2007)**. Cattle dung contains a rumen micro-organism that assists to carry out anaerobic digestion faster, increase the biogas and methane yield **(Zitomer et al., 2008)**. The anaerobic digestion process is normally classified into three different temperature ranges, namely psychrophilic (<20 ºC), mesophilic (20-40 ºC) and thermophilic (>40 ºC) **(El-Mashad et al., 2004)**. The AD is usually carried out as one-stage processes at mesophilic (30-40 ^{o}C) or thermophilic (50-55 ^{o}C) conditions; and running at its optimum temperature range of 25 to 38 ºC mesophilic conditions **(köttner, 2003)**. The mesophilic conditions are greater stability of digestion process, easier to control and utilized in about 95 percent of all digesters. Furthermore, a mesophilic treatment reportedly destroys 99.9% of pathogens **(Erickson et al., 2004)**. Only 30-40% of the organic matter content in waste activated sludge is destroyed in reactors operated at mesophilic temperatures with 10-20 days retention time **(Takashima, 2008)**. Conventional anaerobic digesters require feed material with total solids content (TS) below 10% **(Forster-Carneiro et al., 2008)**. There are two types of digesters: vertical and horizontal digesters. Vertical continuously stirred tank digester is employed in nearly 90% of modern biogas plants in Germany and is the most widely applied digester type for wet digestion **(Weiland, 2010)**. The energy from biogas can be converted to electricity with a typical efficiency of 22-36% **(NREL, 2003)**; 34-40% for large turbines and with an efficiency of 25% for smaller generators **(Tafdrup, 1995)**. A conventional municipal wastewater treatment plant consists of three principal treatment steps: primary (suspended solids removal), secondary (organic pollution removal) and tertiary (nitrogen and phosphorus removal) stages. All steps of wastewater treatment and sludge disposal technologies require energy for pumping, mixing and aeration of wastewater or sludge. Serabium wastewater treatment plant, Ismailia, Egypt, is designed as a secondary treatment plant on an area of 860 feddan (about 361 ha) as an aerated oxidation ponds **(Abdel-Shafy and Salem, 2007)**. The range of the energy intensity of secondary wastewater treatment systems is relatively wide, in average 0.46 kWh/m^3 (Australia), 0.269 kWh/m^3 (China), 0.33-0.60 kWh/m^3 (USA) and 0.30-1.89 kWh/m^3 (Japan). Further, the cost of energy is likely to increase more rapidly than inflation because the expected future difficulties in funding and the high cost of setting up new power plants. For this reason, energy recovery by AD biogas production at wastewater treatment plants can reduced energy costs and represents an important policy lever for sustainability **(Stillwell et al., 2010)**.

This paper presented the basic situation of energy consumption WWTP in Serabium, Ismailia, Egypt. Therefore, the aim of paper was to explore the substrate specific biogas and methane production via $m^3\ kg^{-1}$ TS of mono and co-digestion sludge WWTP Serabium and cattle dung under mesophilic condition and vertical biogas digester in batch experimental. Calculate the total biogas energy kWh and energy recovery as electrical energy kWh_{el} can be produced sewage sludge from one cubic meter treated wastewater in WWTP Serabium using biogas.

2. MATERIALS AND METHODS

2.1. Bench-scale biogas digester

Three bench-scale of cylindrical biogas digester (vertical type) were constructed at the Agricultural Engineering Department, Faculty of Agriculture, Suez-Canal University. Each digester was fabricated from galvanized steel sheet of 1.5 mm thick, 450 mm long and 250 mm diameter (cylindrical shape) with total capacity of 22 liters and actual digestion volume of 20 liters. For feeding the organic wastes (effluent) and rejecting the digested materials, galvanized steel inlet and PVC outlet tubes of 50.8 mm diameter were connected with the digester. To follow up the digestion processes, orifice for releasing the produced gas was located in the digester. A hasp mixer was mounted with the biogas digester and adjusted automatically at 2 minute each one half hour; meanwhile a thermostatic electrical heating unit provided with a pump to adjust and select the temperature inside the digester by the help of water jacket as shown in Fig. (1-A). The temperature of all experiments was selected within the optimum mesophilic bacteria region 36 ^{o}C and the operation was stabilized at 36.0±1.0 ºC. The released biogas was collected in gasholder and its volume was also determined using the wetted displacement with a previously calibrated scale in liter as shown in Fig. (1-B).

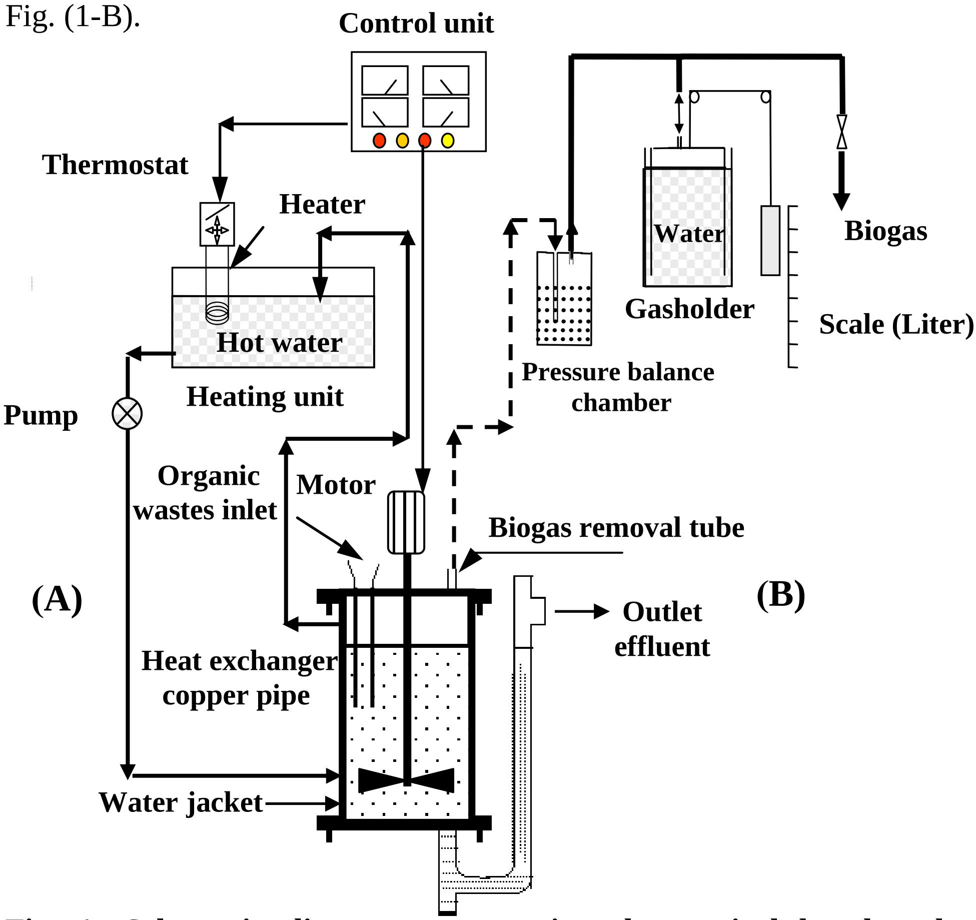

Fig. 1: Schematic diagram representing the vertical bench-scale biogas digester.

2.2. Substrates

2.2.1. Sewage sludge substrate

The sewage sludge used for the experiment was collected from Serabium Wastewater Treatment Plant (WWTP), Ismailia, Egypt. The plant is located 15 km to the south of Ismailia city. It is in operation since 1996 to serve 450,000 populations and average receiving wastewater 107626 m^3/day with average monthly consume energy 1087993 kWh. The plant was designed as a secondary treatment plant on an area of 860 feddans (about 361 ha) as an aerated oxidation ponds **(Abdel-Shafy and Salem, 2007)**. The dry sewage sludge production rate was estimated of 0.225 g L^{-1} of treated wastewater, while the sewage sludge from secondary treatment has total solid (TS) and volatile solid (VS) 5.7 and 4.42%, respectively as mono-fermentation of sewage sludge.

2.2.2. Fresh cattle dung

The fresh raw dung was collected randomly from cattle holding pen unit located in the farm of the faculty of agriculture, Suez-Canal University, Ismailia, Egypt. The TS and VS of fresh raw cattle dung were 11.8 and 8.85%, respectively. The fresh raw dung was diluted by tap water to reach TS 6.8, with VS 5.1%, respectively before putting into the anaerobic digester as mono-fermentation of cattle dung.

2.2.3. Mixture substrates

Due to the calculation of the TS and VS% of mixture and the digester process can confirm the conversion performance of the digester (organic loading rate and the biogas production). Therefore, the mixture of sewage sludge and cattle dung was 1:1 by volume (10 liter sewage sludge and 10 liter fresh raw dung) as co-fermentation. The mixture had final TS and VS concentrations 8.75 and 6.71%, respectively. The experiments were run for 92 days hydraulic retention time (HRT) as batch experiment. The characteristics and chemical composition of sewage sludge, fresh raw dung and the mixture (sewage sludge and cattle dung) were illustrated in Table (1).

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

Parameter	Unit	Sludge	Cattle dung	Mixture
Total solid (TS)	%	5.70	11.80	8.75
Volatile solids (VS)	%	4.42	8.85	6.71
Volatile solids, VS (% of TS)	%	77.54	75.0	76.68
Ash	%	1.28	2.95	2.04
pH value		5.36	7.14	6.44
Organic total carbon, OC (% of TS)	%	45.0	43.5	44.5
Total Nitrogen	%	5.1	1.81	3.42
C:N ratio		9:1	24:1	13:1
Alkalinity as $CaCO_3$	g L^{-1}	4.8	5.9	5.5
Chemical oxygen demand (COD)	g L^{-1}	46.0	61.3	56.3

2.3. Analytical methods and instrumentation

The pH values and temperature of the sewage sludge, cattle dung and mixture inside the bench-scale digester were measured by using Jenway pH hand held meter (model 370 pH/mV). The TS, VS, COD and alkalinity as $CaCO_3$ were analyzed according to standard method for the examination of water and wastewater **(DEV, 1971 and APHA, 2012)**. While the concentration of available nitrogen was determined using Kjaldhal and organic carbon can be calculated using the following equation according to **(Black et al., 1965)**.

$$Total\,organic\,carbon\,\% = \frac{VS\,(\%\,of\ TS\,)}{1.724} \tag{1}$$

2.3.1. Methane percentage

The biogas was fractionated in a percentage i.e. methane and CO_2 percentage using the Potassium hydroxide 40% **(Okeke and Ezekoye, 2006; Abdel-Hadi, 2008)**. The performance of each biodigester was assessed with respect to cumulative volume of biogas produced and corrected according to standard pressure (760 mm Hg) and temperature (0 ^{o}C) STP **(Hansen et al., 2004)**.

2.3.2. Calculation of potential biogas energy and electrical energy

If the biogas production expressed in Nm^3 was known, from it the lower heating value of biogas energy production was calculated using equation (2). The electrical energy can be calculated if the converted efficiency

(η_{el}) of the combined heat and power (CHP) motor was known using the equation (3) according to **(Parmlind, 2014)**.

Potential biogas energy

$$B_{energy} = B * \% M * M_{energy} \tag{2}$$

Where:

B_{energy} : *Biogas heating energy, kWh*

B : *Biogas quantity by normal cubic meter at STP, Nm^3*

M : *Methane, %*

M_{energy} : *Energy value of pure methane, 9.81 kWh/Nm^3 according to* **(Schnürer and Jarvis, 2010)**

Electrical energy

$$E_{energy} = B_{energy} * \eta_{el} \tag{3}$$

Where:

E_{energy} : *Electrical energy, kWh_{el}*

B_{energy} : *Biogas heating energy, kWh*

η_{el} : *Converted efficiency of (CHP) motor, 35% according to* **(Tafdrup, 1995 and NREL, 2003)**

3. RESULTS AND DISCUSSION

3.1. Biogas and methane production

Fig. (2) present the cumulative biogas production curves during the patch experiment 92 day retention time which have a tendency to obey sigmoid function (S-curve) as generally occurred in batch growth curve and as stated by **Budiyono et al. (2009)**. In most cases, biogas and methane production are very slow at the beginning and the end period of observation. This is predicted due to the biogas production rate in batch condition is directly corresponds to specific growth rate of methanogenic bacteria in the bio-digester **(Nopharatana et al., 2007)**. The cumulative biogas productions were 0.202, 0.209 and 0.320 m^3 for mono-digestion sewage sludge and cattle dung and co-digestion mixture, respectively.

The methane percentage in the batch experiment increased fast during the initial 17 days and reached to 48.4 and 64.7% mono-digestion sewage sludge and cattle dung, respectively; 62.8% co-digestion of mixture. Thereafter, it increased gradually in the following days. By contrast, a higher carbon dioxide percentage was obtained at the initial of digestion.

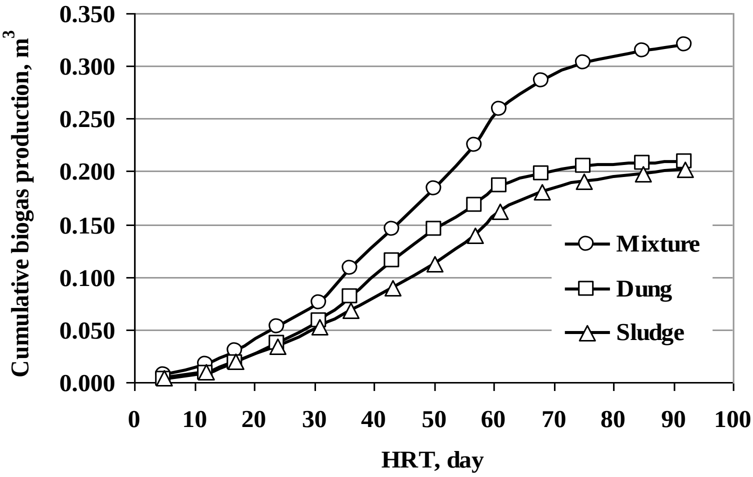

Fig. 2: Cumulative production of biogas during the experiment.

The carbon dioxide percentage decreased gradually along with the increase of methane percentage. The highest methane percentages of 65.7 and 71.2% were measured in mono-digestion sewage sludge and cattle dung at day 61 and 85, respectively, while 70% was measured in co-digestion of mixture at day 75 as shown as in Fig. (3). The typical biogas composition obtained during anaerobic digestion; comprises of methane 55-75%, carbon dioxide 30-45% **(Igoni et al., 2008)**. The average methane percentage was 57.3, 63.5 and 62.9% for sludge, cattle dung and mixture, respectively recovered in this experiment was within the range of methane percentage in typical biogas.

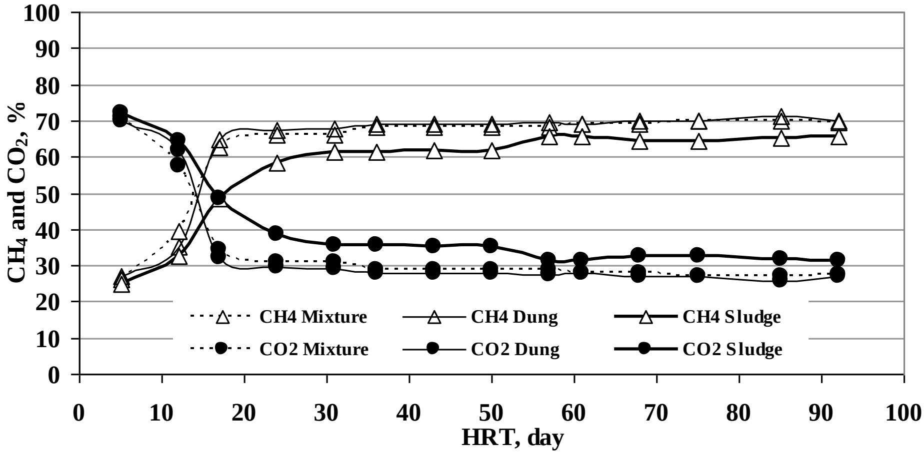

Fig. 3: Methane and carbon dioxide percentages.

3.1.1. Specific biogas and methane production

The cumulative biogas production per m^3 and the average methane percentage was recorded in Table (2). The results show that the specific biogas production values were 0.228 and 0.205 m^3 kg^{-1} VS while the methane percentages were 57.3 and 63.5% for mono-digestion sewage sludge and cattle dung, respectively. However, the specific biogas production was increased with co-digestion of mixture, and recorded 0.238 m^3 kg^{-1} VS. On the other hand, the specific biogas production from co-digestion mixture increased by 4.4 and 16.1% comparing with mono-digestion sludge and cattle dung, respectively. The result agrees with **(Zitomer et al., 2008)**.

Table 2: The substrate specific biogas and methane production, m^3 kg^{-1} TS substrates added of sludge wastewater, dung and mixture.

Treatment	Input TS, kg	Input VS, kg	Cumulative biogas, m^3	Average methane, %	Biogas	Methane	Biogas	Methane
					m^3 kg^{-1} TS		m^3 kg^{-1} VS	
Sludge	1.14	0.884	0.202	57.3	0.177	0.101	0.228	0.131
Cattle dung	1.36	1.020	0.209	63.5	0.153	0.097	0.205	0.130
Mixture	1.75	1.342	0.320	62.9	0.183	0.115	0.238	0.150

A considerable number of studies have been conducted to investigate anaerobic mono-digestion of sludge. Many studies have reported similar specific biogas and methane production in the range of 0.200-0.300 m^3 kg^{-1} VS and around 0.140-0.200 m^3 kg^{-1} VS, respectively **(Kumar, 2005 and Malik, 2007)**.

Another way to calculate the specific biogas and methane production per sewage sludge one cubic meter treated wastewater were 0.040 and 0.023 m^3, respectively as illustrates in Table (3).

Table 3: The substrate specific biogas and methane production, m^3 kg^{-1} TS and m^3/m^3 wastewater.

Treatment Mono-fermentation	Sludge, kg TS/m^3	Average methane, %	Biogas	Methane	Biogas	Methane
			m^3 kg^{-1} TS		m^3/m^3 wastewater	
Wastewater	0.225	57.3	0.177	0.101	0.040	0.023

The pH of the digester is a function of the concentration of bicarbonate alkalinity of the system, and the amount of carbon dioxide produced. The measured pH values for anaerobic digestion of sewage sludge, cattle dung and mixture at experimental intervals are shown in Fig. (4). The pH for sewage sludge started from 5.36 and then increased up to 7.54, for cattle dung started from 7.14, decreased to 5.88 and raised again to 7.14, while in the case of mixture the pH started from 6.44, decreased to 6.09 and raised again to 7.24. The best methane percentages were 65.7, 71.2 and 70% occurs at pH 7.3, 7.2 and 7.1 for sewage sludge, dung and mixture, respectively. This agrees with the results of **(Bitton, 1994; Van Haandel and Lettinga, 1994),** that the most methanogenic bacteria function optimally at pH 7 to 7.2 and the rate of methane production declines at pH values below 6.3 or exceeding 7.8.

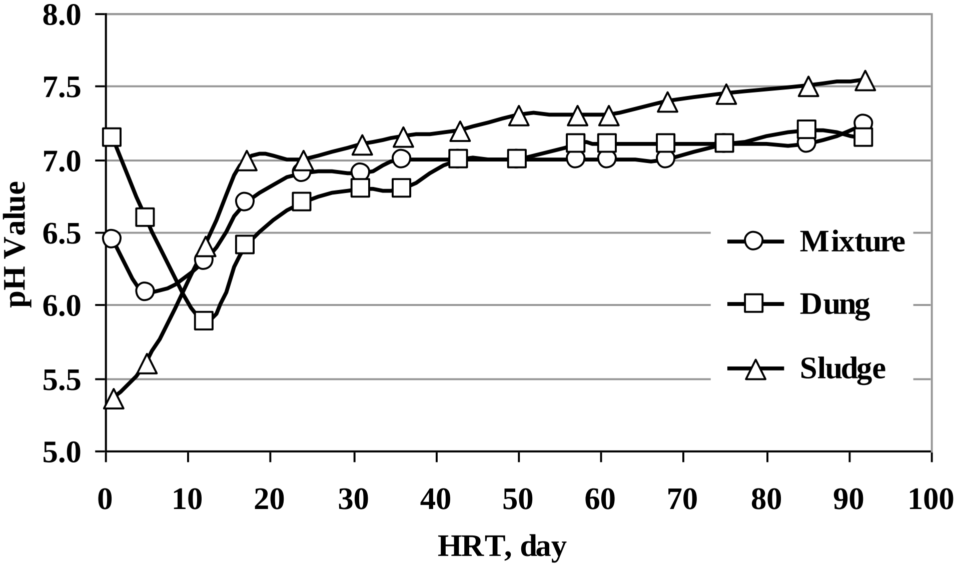

Fig. 4: pH values intervals during the experiment for sewage sludge, cattle dung and mixture.

3.2. Degradation of organic carbon

Methods of measurement degradation (expressed as organic carbon degradation, %) are based on biogas production and methane percentage or substrate depletion such as VS, COD and etc. **(Rozzi and Remigi, 2001)**. Fig. (5) show the degradation organic carbon percent intervals during the experiment. The degradation percent was increased during running the experiments; on the other hand the organic total solids as volatile (VS) decreased due to microbial decomposition of organic matter into methane and carbon dioxide. The VS at the beginning of the time period of the experiment was 4.42, 5.1 and 6.71% decreased to 3.08, 2.92 and 3.65% at the end of experiment for sludge, cattle dung and mixture, respectively. At the same time the COD was decreased due to the anaerobic bacteria, which break down the VS and reduce the level of chemical oxygen demand in the wastewater as shown as in Fig. (6). Therefore, the COD was 46.0, 61.3 and 56.3 g L^{-1} at the beginning experiment decreased to 34.7, 41.2 and 39.0 g L^{-1} at the end of experiment for sludge, cattle dung and mixture, respectively; Table (4) illustrate the VS and COD at the end of experiment. Furthermore, the average degradation percentage was 21.8, 28.4 and 26.2% proportional with the average methane percentage 57.3, 63.5 and 62.6% for sludge, cattle dung and mixture, respectively.

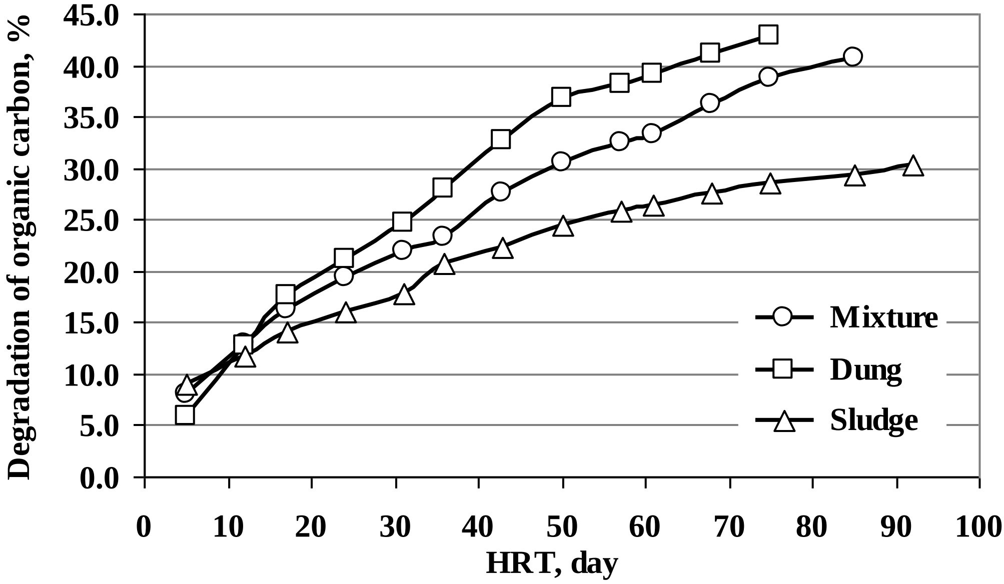

Fig. 5: Degradation of organic carbon for sewage sludge, dung and mixture.

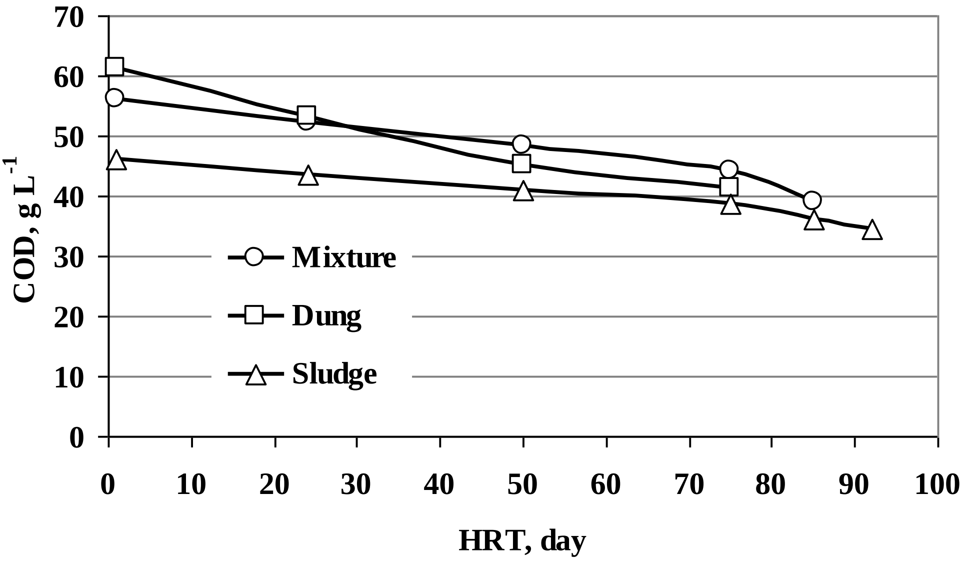

Fig. 6: COD intervals during the experiment for sewage sludge, cattle dung and mixture.

Table 4: Final composition of sewage sludge, cattle dung and mixture effluent.

Parameter	Unit	Sludge	Cattle dung	Mixture
Total solid (TS)	%	4.40	4.37	5.31
Volatile solids (VS)	%	3.08	2.92	3.65
Digestibility of TS	%	30.30	40.00	41.00
pH value		7.54	7.14	7.24
Organic total carbon, OC (% of TS)	%	40.60	38.75	39.87
C:N ratio		16:1	18:1	24:1
Alkalinity as CaCO3	$g\ L^{-1}$	5.95	6.81	6.70
Chemical oxygen demand (COD)	$g\ L^{-1}$	34.70	41.2	39.0

3.3. Potential biogas energy and electrical energy

Energy demand of wastewater treatment technology depends on the location of the plant, size, organic or hydraulic load, type of the treatment process and the aeration system, effluent quality requirements, age of the plant, experience of its managers, etc. The average energy consumption of

Serabium wastewater treatment plant, Ismailia, Egypt, was 0.337 kWh/m^3. If the data was compared with data in other wastewater treatment plant, it was higher than, compared to 0.269 kWh/m^3 in China and less than compared to 0.33-0.60 kWh/m^3 (USA) and 0.30-1.89 kWh/m^3 (Japan) according **(WEF, 2009; Yang et al., 2010; Plappally and Lienhard, 2012)**. The potential biogas energy and electrical energy can be produced sewage sludge from one cubic meter treated wastewater was 0.226 kWh and 0.079 kWh$_{el}$, respectively according to equation (2 and 3) and Table (5).

Table 5: The biogas and electrical energy which can be produced from one cubic meter wastewater.

Treatment	Methane, m^3/m^3	M_{energy}, kWh/m^3	B_{energy}, kWh/m^3	η_{el}, %	$E_{Eenergy}$, kWh$_{el}$/m^3
Mono-fermentation	waste-water		waste-water		waste-water
Wastewater	0.023	9.81	0.226	35	0.079

On the other hand, the biogas production from sewage sludge can be energy recovery about 23.4% of electricity consumption in wastewater treatment plant. The result in agreement with **(Dereix et al., 2006; Crawford and Sandino, 2010)**.

4. CONCLUSIONS

- The specific biogas production values were 0.177 and 0.153 mono-digestion of sewage sludge and cattle dung, respectively and 0.183 m^3 kg-1 TS co-digestion for mixture (sewage sludge and cattle dung).
- The average degradation percentages were 21.8, 28.4 and 26.2% proportional with the average methane percentages of 57.3, 63.5 and 62.6% for sewage sludge, cattle dung and mixture, respectively.
- The COD values were 46.0, 61.3 and 56.3 g L-1 at the beginning of experiment decreased to 34.7, 41.2 and 39.0 g L-1 at the end of experiment for sewage sludge, cattle dung and mixture, respectively.
- The average energy consumption of Serabium wastewater treatment plant was 0.337 kWh/m^3.
- The potential biogas energy and electrical energy which can be produced from one cubic meter wastewater were 0.226 kWh and 0.079 kWhel, respectively.

- Production of electrical energy from biogas conducted in wastewater treatment plant leads to coverage of approximately 23.4% of the total demand of electricity.
- Such solutions should become an alternative to the Egyptian plants. Technological chains of sewage sludge treatment technology with the use of biogas as an unconventional energy source can be inspiration in the search for optimum solutions in the wastewater treatment economy.

5. REFERENCES

Abdel-Hadi, M. A. (2008): A simple apparatus for biogas quality determination. Misr J., Ag. Eng. 25(3): 1055-1066.

Abdel-Shafy, H. I. and Salem, M. A. (2007): Efficiency of Oxidation Ponds for Wastewater Treatment in Egypt. NATO Science for peace and Security Series- C: Environmental Security, Wastewater Reuse - Risk Assessment, Decision-Making and Environmental Security, ISBN: 978-1-4020-6027-4, 175-184.

American Public Health Association, APHA (2012): Standard methods for the examination of water and wastewater 22nd edition, American Public Health Association, Washington DC, USA.

Bitton, G. (1994): Wastewater Microbiology. ISBN 0471309850, Wiley-Liss, New York, USA, 478 p.

Black, C. A.; Evans, D. D., Evsminger, I. E., Clerk, F. E. and White, J. L. (1965): Methods of Soil Analysis: Part 1, American Society of Agronomy, Inc., Madison, USA.

Bolzonella, D.; Pavan, P.; Battistoni, P. and Cecchi, F. (2006): Anaerobic co-digestion of sludge with other organic wastes and phosphorous reclamation in BNR wastewater treatment plants. Water Science and Technology, 53(12): 177-186.

Budiyono, B.; Widiasa, I. N.; Johari, S. and Sunarso, S. (2009): Influence of inoculum content on performance of anaerobic reactors for treating cattle manure using rumen fluid inoculum. International Journal of Engineering and Technology, 1(3): 109-116.

Crawford, G. and Sandino, J. (2010): Energy efficiency in wastewater treatment in North America: a compendium of best practices and case studies of novel approaches. IWA Publishing, London. ISBN: 1843393972, 80 p.

Davidsson, Å.; Appelqvist, B.; Gruvberger, C. and Hallmer, M. (2007): Anaerobic digestion potential of urban organic waste: a case study in Malmö. Waste Management Research, 25, 162-169.

Dereix, M.; Parker, W. and Kennedy, K. (2006): Steam-explosion pretreatment for enhancing anaerobic digestion of municipal wastewater sludge. Water Environ Res., 78(5): 474-485.

DEV (1971): Deutsche einheitesverfahren zur wasser- und schlammuntersuchungung. Verlag Chemie, S. 2-6, Weinheim, Germany.

El-Mashad, H. M.; Zeeman, G.; Van Loon, W. K. P.; Bot, G. P. A. and Lettinga, G. (2004): Effect of temperature and temperature fluctuation on thermophilic anaerobic digestion of cattle manure. Bioresource Technology, 95: 191-201.

Erickson, L. E.; Fayet, E.; Kakumanu, B. K. and Davis, L. C. (2004): Anaerobic Digestion. National Agricultural Biosecurity Center, Kansas State University

Forster-Carneiro, T.; Pérez, M. and Romero, L. I. (2008): Influence of total solid and inoculum contents on performance of anaerobic reactors treating food waste. Bioresource Technology, 99: 6994-7002.

Ghazy. M.; Dockhorn, T. and Dichtl, N. (2009): Sewage sludge management in Egypt: current status and perspectives towards a sustainable agricultural use. World Academy of Science Engineering and Technology, 57: 299-307.

Hansen, T. L.; Schmidt, J. E.; Angelidaki, I.; Marca, E.; Jansen, J.; Mosbaek, H. and Christensen, T. H. (2004): Method for determination of methane potentials of solid organic waste. Waste Management, 24: 393-400.

Igoni, A. H.; Ayotamuno, M. J.; Eze, C. L.; Ogaji, S. O. T. and Probert, S. D. (2008): Designs of anaerobic digesters for producing biogas from municipal solid-waste. Applied Energy, 85: 430-438.

köttner, M. (2003): Integration of biogas technology, organic farming and energy crops. The future of biogas in Europe II, European biogas workshop. October 2nd to 4th, 2003, University of Southern Denmark esbjerg / Denmark.

Kumar, S. (2005): Studies on efficiencies of bio-gas production in anaerobic digesters using water hyacinth and night-soil alone as well as in combination. Asian Journal of Chemistry, 17: 934-938.

Malik, A. (2007): Environmental challenge vis a vis opportunity: The case of water hyacinth, Environment International, 33(1): 122-138.

National Renewable Energy Laboratory, NREL (2003): Gas-Fired Distributed Energy Resource Technology Characterizations. U.S. Department of Energy Laboratory, Midwest Research Institute, November 2003. NREL/TP-620-34783.

Nopharatana, A.; Pullammanappallil, P. C. and Clarke, W. P. (2007): Kinetics and dynamic modeling of batch anaerobic digestion of municipal solid waste in a stirred reactor, Waste Management, 27: 595-603.

Okeke, C. E. and Ezekoye, V. A. (2006): Design, construction, and performance evaluation of plastic biodigester. The Pacific J. Sc. Tec., 7(2), Nsukka, Nigeria.

Parmlind, E. (2014): Energy analysis of farm-based biogas plants in Sweden. Examensarbete (Institutionen for energi och teknik), SLU, Swedish University of Agricultural Sciences. ISSN 1654-9392, 43 p.

Plappally, A. K. and Lienhard, V. (2012): Energy production for water production, treatment, end use, reclamation, and disposal, Renew. Sust. Energ. Rev., 16, 4818.

Rozzi, A. and Remigi, E. (2001): Anaerobic biodegradability: Conference Proceeding. In: 9th World Congress, Anaerobic digestion 2001, Workshop 3 Harmonisation of anaerobic activity and biodegradation assays, Belgium.

Schnürer, A and Jarvis, A. (2010): Microbiological Handbook for Biogas Plants. Swedish Waste Management U2009:03 Swedish Gas Centre Report 207, 138 p.

Stillwell, A. S.; Hoppock, D. C. and Webber, M. E. (2010): Energy Recovery from Wastewater Treatment Plants in the United States: A

Case Study of the Energy-Water Nexus. Sustainability, special issue Energy Policy and Sustainability, 2(4): 945-962

Tafdrup, S. (1995): Viable energy production and waste recycling from anaerobic digestion of manure and other biomass materials. Biomass and Bioenergy, 9(1-5): 303-314.

Takashima, M. (2008): Examination on process configuration incorporating thermal treatment for anaerobic digestion of sewage sludge. J Environ Eng., 134: 543-549.

Van Haandel, A. and Lettinga, G. (1994): Anaerobic Sewage Treatment- A Practical Guide for Regions with Hot Climate. John Wiley & Sons. Inc., Chichester, UK, 226 p.

Water Environment Federation, WEF (2009): Energy conservation in water and wastewater facilities, 1st Ed., WEF Press, McGraw Hill, New York, ISBN-10: 0071667946, 400 p.

Weiland, P. (2010): Biogas production: current state and perspectives. Applied Microbiology and Biotechnology, 85(4): 849-860.

Yang, l.; Zeng, S.; Chen, J.; HE, M. and Yang, W. (2010): Operational energy performance assessment system of municipal waste water treatment plants, Water Sci. Tech., 62(6): 1361.

Zitomer D. H.; Adhikari, P.; Heisel, C. and Dineen, D. (2008): Municipal anaerobic digesters for codigestion, energy recovery, and greenhouse gas reductions. Water Environment Research, 80(3): 229-237.

الملخص العربى

إمكانية إنتاج الغاز الحيوي من الحمأة النشطة وأستعادة الطاقة لمحطات معالجة مياه الصرف الصحي

محمد علي عبد الهادي*

يعتبر التخمر اللاهوائي لأنتاج الغاز الحيوي احد التطبيقات لاستعادة الطاقة من الحمأة الناتجة من محطات معالجة الصرف الصحي والتي تقدر في مصر بحوالي ٢ مليون طن حمأة جافة / سنوياً.

تمت دراسة معملية لأنتاج الغاز الحيوي من الحمأة الناتجة من محطة معالجة مياه الصرف الصحي سرابيوم - محافظة الأسماعيلية - مصر, بالوحدة التجريبية للغاز الحيوي بقسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس.

***أستاذ مساعد بقسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس.**

حيث أستخدمت ثلاث مخمرات رأسية مصنعة من الحديد المجلفن بسمك ١,٥مم ومتساوية القطر ٢٥٠ مم والارتفاع ٤٥٠ مم بحجم كلي ٢٢ لتر وحجم تخمر صافي ٢٠ لتر. تم استخدام حمأة الصرف الصحي بنسبة ٥,٧% مادة جافة الكلية (TS) كتخمر احادي للمخمر الأول وروث الماشية بنسبة ١١,٨% TS بعد تخفيفة بالماء الي ٦,٨% TS كتخمر احادي للمخمر الثاني بينما تم استخدام خليط من الحمأة والروث قبل التخفيف بنسبة خلط ١:١ بالحجم بنسبة ٨,٧٥% TS كتخمر مختلط للمخمر الثالث. تمت تغذية المخمرات بنظام دفعة واحدة بحجم ٢٠ لتر لكل مخمر تحت درجة حرارة تخمر ثابتة في مدى بكتريا الميزوفيليك ٣٦م^{o} مع التقليب دقيقتين لكل نصف ساعة. تم تقدير % TS و% VS (المادة الجافة العضوية) معملياً في المواد المتخمرة لحساب نسبة تحلل المادة العضوية خلال وقت الاستبقاء ٩٢ يوم كما تم تقدير نسبة الكربون:النيتروجين (C:N) والقلوية (Alkalinity as $CaCO_3$) والطلب علي الأوكسجين الكميائي (COD) كما تم قياس رقم الأس الهيدروجيني (pH) ودرجة الحرارة وكمية الغاز الحيوي الناتج باللتر بالأزاحة الحجمية ونسبة غاز الميثان عن طريق محلول كميائي ٤٠% هيدروكسيد بوتاسيوم خلال التجربة في المعاملات تحت الدراسة. كما تم حساب كمية الغاز الحيوي والميثان بالمتر المكعب المتحصل عليها لكل كجم مادة جافة كلية أو للحمأة الناتجة من م^{٣} مياه صرف معالجة (m^3 kg^{-1} TS) و (m^3/m^3) علي الترتيب.

وقد توصلت النتائج إلي:

١- كمية الغاز الحيوي الناتجة كانت ٠,١٧٧, ٠,١٥٠ م^{٣}/ كجم مادة عضوية جافة للحمأة وروث الماشية علي الترتيب بينما كانت ٠,١٨٣ م^{٣}/ كجم مادة عضوية للخليط.

٢- كانت متوسط نسبة التحلل ٢١,٨, ٢٨,٤ و ٢٦,٢% في علاقة طردية مع متوسط نسبة الميثان ٥٧,٣, ٦٣,٥ و٦٢,٦% للحمأة وروث الماشية والخليط علي الترتيب.

٣- كانت كمية (COD) في بداية التجربة ٤٦,١, ٦١,٣ و ٥٦,٣ قلت الي ٣٤,٧, ٤١,٢ و ٣٩,٠ جرام/لتر في نهاية التجربة للحمأة وروث الماشية والخليط علي الترتيب.

٤- كان متوسط استهلاك الطاقة في محطة معالجة مياه الصرف الصحي بسرابيوم ٠,٣٣٧ كيلو وات ساعة/ م^{٣} مياه صرف صحي معالجة.

٥- قدرت كمية طاقة البيوجاز والطاقة الكهربائية التي يمكن انتاجها من حمأة م^{٣} مياه صرف صحي ٠,٢٢٦ و ٠,٠٧٩ كيلو وات ساعة علي الترتيب. والتي تغطي ما يقرب من ٢٣,٤٪ من إجمالي الطلب على الكهرباء في محطة المعالجة.

٦- أستعادة الطاقة بانتاج الغاز الحيوي من الحمأة يمكن أن يكون مصدر بديل للطاقة الغير تقليدية يفي بجزء من متطلبات الطاقة في محطات الصرف الصحي في مصر.