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ENHANCING THE PRODUCTION OF BIO GAS AND BIO ELECTRICITY

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ABSTRACT

This study is considered for enhancing the production of biogas and bioelectricity produced from sludge in Sewage water treatment plant –Chennai. The sewage water collected from 44areas in Chennai under the pipe lines of pump. Then the treatment of pretreatment, primary and secondary treatments are taking place for purifying the contaminated water. This treatment are used to reduce the organic loading, total suspended solids and grease, in secondary treatment the sludge thickened is formed .The sludge thickened are pumped to the digester by the way of top, middle and bottom of the pipe lines, continuously the sludge mixed well, Alternatively the digester maintains at ideal condition and flow of mixing conditions .In this stage we are adding the enzyme in the digester.Our Bio-Enzyme is having *Trehalose* it is specialized carbohydrate for developing growth factor *Arechea* bacteria which is sole responsible in the formation of Methane gas. Three processes are involved in this gas formation - Hydrolysis, acidogenesis and methanogenesis.,DDuring the process of methanongesis the methane gas *(CH4)*is formed. During that process the enzyme react with methanongesis process and enhancing the methane gas production. All the biogases collected and passed through the pipe line to the Gasholder. After that the gases passed through the scrubbing system for removal of H_2S (Hydrogen sulphide gas). The volume of H_2S measured it should be less 10%, and then the gas passed to the gas engine, the gas engine convert the gas energy to electrical energy.

KEYWORDS : Sludge, Digester, Biogas, Bio-Enzyme, Bioelectricity.

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INTRODUCTION

Microbial fuel cell technology is a new type of renewable and sustainable technology for electricity generation since it recovers energy from renewable materials that can be difficult to dispose of, such as organic wastes and wastewaters. In the present contribution we demonstrated electricity production by beer brewery wastewater, sugar industry wastewater, dairy wastewater, municipal wastewater and paper industry wastewater. Up to 14.92 mA current and 90.23% COD(Chemical Oxygen Demand) removal was achieved in 10 days of operation.In today's energy demanding life style, need for exploring and exploiting new sources of energy which are renewable as well as eco-friendly is a must. In rural areas of developing countries various cellulosic biomass (cattle dung, agricultural residues, etc.) are available in plenty which have a very good potential to cater to the energy demand, especially in the domestic sector. In India alone, there are an estimated over 250 million cattle and if one third of the dung produced annually from these is available for production of biogas, more than 12 million biogas plants can be installed [1].Although the concept of electricity production from bacteria was conceived nearly a century ago by Potter [2], only recently the technology has been sufficiently improved to make it useful as a method for energy generation[3, 4]. One near-term application of MFCs will be to produce electricity from wastewater[5, 6], providing a new way to simultaneously treat wastewater while obtaining a source of clean and renewable energy[7, 8]. A major environmental issue in today is associated with the release of green house gases1. Fossil fuels are the major contributors for green house effect and at the same time its depletion occurs rapidly in each advancing year. In order to minimize this global energy demand and environmental impacts, an alternate energy source is needed2, 3. The production of biogas from biomass has been identified and used as renewable high energy biofuel from past few decades for various purposes. Biogas production technology in India has been started from 1950s whereas at the moment this technology never becomes popularized. It has been early demonstrated that biogas production from crop residues is economically feasible on a farm-scale level (50–500 kW) [2]

METHODOLOGY

Distribution chamber IV

Sludge from primary clarifiers is distributed into gravity sludge thickness of pass-1&2 through distribution chamber IV of 2.30 m dia x 5.14m TD. Sludge from the primary clarifiers is received by pumping or by gravity to this chamber. The dilution water pumped from dilution water pump house is also received in this chamber, to prevent any bad smelling of the sludge in the thickener. The distribution chamber is designed for 688.51 m^3/h in order to cater to an additional thickener that may be added in phase-II. The flow enters the thickener of phase-I through the penstock gate at the bottom floor level of the distribution chamber. Provision for installing gate for feeding phase-II Thickener is provided at the bottom floor level of the distribution chamber.

Gravity Sludge Thickener 110

A sludge thickener of 30.00 m (Dia) x 3.50 m is provided for the co-thickening of primary sludge and excess activated sludge, received from primary clarifiers. The thickener is of radial flow type and ensures the thickening of sludge to about 5%. The dilution water ensures that no odors problem occurs in the thickener. The supernatant from the thickener overflows the V-notch weir at the periphery and is received in the supernatant cum filtrate sump. The thickener is equipped with a mechanical solid picket and fence type scraper mechanism (TM 101 A) to scrape the thickened sludge to the central pit. From here it is discharged into the Thickened sludge sump (S 105) of size 7.2 m (L) x 1.0 m (W) x 1.25 m (LD-Liquid depth) once in 4hours for a period of approximately 2 hours. The scraper mechanism is provided with torque switch which trip the scraper motor in case of overloading or obstruction of the scraper arms, with alarm. The thickened sludge sump is equipped with a low level switch with alarm which trips the Thickened sludge pumps (TSP

(Thickened Sludge Pump) 105 A/B/C-2W+1S), each of capacity 45 m3/hr that take suction from this sump and feed the digesters.

Sludge Digesters, T 111 A/B

The two Sludge digesters each of New 20.6 m Dia * 6.42 m H have been constructed to receive the thickened sludge. The thickened sludge undergoes anaerobic decomposition in the absence of air in the closed dome type digesters, producing biogas**.** Three processes involved in sludge digester are;

1. Hydrolysis
2. Acid formation
3. Methane formation.

1. Hydrolysis

• In the first stage of digestion, the complex organic matters like protein, Cellulose, lipids are converted by extra cellular enzymes into simple soluble organic matter[9].

•

$$\longrightarrow \quad \text{Complex organic matter} \xrightarrow[\text{Enzymes}]{\text{Cellular}} \text{simple soluble organic matter}$$

2. Acid formation

• In the second stage, the soluble organic matter is converted by acetogenic bacteria into acetic acid, hydrogen, carbon-dioxide, and other low molecular weight organic acids[10, 11].

$$\text{Soluble organic matter} \xrightarrow[\text{Bacteria}]{\text{Acetogenic}} \text{acetic acid} + H2 + Co2 + \text{lower molecular weight (organic acids)}$$

3. Methane formation

- In the third stage, two groups of methanogenic bacteria, strictly anaerobic, are active. While one group converts acetate into methane and bicarbonate[12, 13.]

$$\text{Acetate} \xrightarrow[\text{Bacteria}]{\text{Methanogenic}} CH4 + HCo3$$

- The other group converts hydrogen and carbon dioxide into methane [14].

$$4H2 + Co2 \longrightarrow CH4 + 2H2o$$

The feeding of the digesters with the thickened sludge takes place through sluice valves in the individual digesters. The digested sludge withdrawal pipe from the bottom of the digester is extended into the sludge-balancing tank. The digesters are provided with a telescopic bleed arrangement. This arrangement can be adjusted to the top water level of the digester to allow the required quantity of the supernatant to be drawn off and sent to the Distribution Chamber-I. The pH measurement is an essential check on the operation of the digested. A tapping is provided from the discharge of the digested mixing pumps from which sludge continuously flows into a pot. The sampling pot is fitted with a pH meter, which measures the pH of the digester contents which is re-circulated, and gives alarms at high and low pH. Temperature indicators are provided in the suction lines of Digester Mixing Pumps to know the temperature of the digester contents. Each Digester is provided with 3 numbers sampling points for sampling the consistency of the Digester contents at various depths, during the final lap of settling period. A pressure safety valve with an inbuilt flame arrestor is provided on the dome of each digester. The pressure safety valve vents any pressure buildup over the design value of 250mm water column and prevents the occurrence of vacuum condition also by letting in atmospheric air. The inbuilt flame arrestor prevents the ingress of any external source of heat into the Digester. The biogas produced from each Digester is measured in a gas flow meter before sending to the Gas Holder. Flame arrestors are provided in the gas lines close to the digesters and also at the inlet of Gas Holder. The pumping of thickened sludge to the Digesters is staggered and the supernatant from the Digester flows directly to the distribution chamber of Primary Clarifiers, by gravity. The Digester mixing pumps run continuously, turning over the contents of each Digester in 4 hours' time, then allowed for 2 hours settling and 2 hours feeding time. The sequence of digester operation is staggered so that when one digester is in feeding cycle, the other digester will be under mixing cycle followed by settling and the cycle continuous. For those digesters, a pump house is provided to house (4W+2S) each of 380 cum/h Digester mixing pumps to ensure the turnover of digester contents in 4 hours' time. The 4 nos. working pumps run continuously, mixing the digester contents, alternatively for 4 hours cycle of sludge mixing. Each digester is having a sludge mixing cycle of 4 hours 3 times in a day. The sludge recirculation lines are provided with branching lines with isolation valves, which are used for scum breaking inside the digester.

Bio-Enzyme

The Bio-Enzyme mixed to the digester cylinder and it will react with only methanogenesis process. The enzymes have a capacity to increase the methane gas production from the digested sludge. Our Bio-Enzyme is having *Trehalose* it is specialized carbohydrate for developing growth factor *Arechea bacteria* which is sole responsible in the formation of Methane gas. In the bio-chemical reaction symbiotic function is necessary for accommodating Aerobic end anaerobic Bacterium. In the absence of oxygen environment. Our Enzyme having chemical structure of so many OH radicals of Hydrogen Iron formation very tremendous in this reaction. Hence it will maintain the function continuously during temperature and P^H variation. Normally Arechea bacterium needs minimum 33ºC up to maximum50ºCtheir function. The entire reaction control by our enzyme. If room temperature falls it will support the Arechea Bacterium to function at any temperature below the minimum level of minus degree it will be activated by the enzyme in this process. This is the peculiar character of our enzyme.

Specification

1. Carbohydrate	10%
2. Conjugated Protein	16%
3. Protein	33%
4. Bio–enzyme	21%
5. Additives	20%
	100%

Self-Life of Bio-Enzyme

We have developed a technology to sustain the activation for 12 months of our Bio – Enzyme. Methane gas formation has been enhanced and consumption 18 to 20% less than we compare to regular bio-gas.

Gas Holder GH 101A, Gas Burner GB 01 & Gas Engine

A bell type gas holder of 12 hours storage capacity is provided in a RCC tank (T 144). Provision is made to fill up the tank with water. The gas holder is designed to roll up the sides of the RCC tank on guide a rails when the biogas produced in the digesters enters the gas holder.

A limit switch with alarm is fitted to to the guide rails of Gas Holder. When the holder raises and touches the high level the solenoid valve controlling the pilot burner is opened and the gas flow is diverter throw a motorized BFV to the gas burner for flaring the excess gas. The gas burner has adequate capacity to burn off the gas produced by the digesters of Phase-I. When the level becomes slow, the blowers that boost the gas for use in the gas engines are tripped manually. A pressure relief valve the DG set of 1000kVA rating is the radiator cooled type and develops 1180 BHP (Boiler Horse Power) under NTP (Normal Temperature and Pressure) conditions @ 1500 RPM (Revolutions per minute) coupled to a standard design insulated alternator. It is mounted on a common iron base frame. It is also provided with 4 x 12V batteries with leads, fuel tank of 990 liters capacity and residential silencers. Hand pump and hose are also provided for diesel. Anti-Vibration Mount pads are provided for vibration protection. The protective functional relay and metering panel are provided monitoring the DG's output and protecting the DG against voltage surges. The synchronizing panel is provided for matching the frequency and voltage of the DG output with that of the gas engine/ EB power supply.

Purpose of Gasholder

- To store the biogas produced in the digesters.
- Flame arrestors are also provided on the dome of the gas holder.
- Drip trap is provided on the biogas line to remove the moisture from saturated biogas by the baffling arrangement in the trap.

Purpose of Gas Engine

- Biogas is utilized for production of power with the the help of biogas engine.
- The power produced by the gas engine / DG set will used for running the drives of STP(Sewage Treatment Plant) and if short phase it is met by TNEB(Tamilnadu Electricity Board).
- Biomass supplies the required biogas flow to gas engine which runs as per the load condition.
- Biogas from scrubber goes to gas mixer (where gas and air get mixed),then goes to turbo charger (suction of gas and exhaust of gas , then goes to inter cooler for cooling purpose), then we have throttle valve next to that engine coupled with alternator and then gas engine air.
- The required quantity of biogas from gas holders is boosted up in pressure by biomass and sent through a wet scrubber for the reduction of concentration of H_2S from 1% to 0.1%.

H_2S Scrubbing System

The scrubbing system consists of an aerobic reactor with an absorber and a sulfur recovery unit. It treats H_2S containing biogas by washing the gas converting the supplied biologically to elemental sulfur.

Absorber

For desulphurization of biogas a packed column as absorber is used. Alkaline water is charged into system initially, this is used as a solvent to absorb H_2S content in Biogas. This alkaline water is almost free of sulfide and contains suspended sulfur, which increases the absorption of H_2S in the absorbers. By this absorption process almost all H_2S can be removed from the gas.

Aerobic Sulphide Reactor

In the aerobic reactor, the sulfides are oxidized by microorganism into elemental sulfur. A small part (less than 10%) of the sulfides is oxidized to sulfate. More than 90% of the alkalinity used in the absorber is regained and recycled to the absorber through washing water. The aerobic reactor is having an aeration system. A small part of the effluent is treated in the sulfur recovery unit to remove the formed sulfur. To prevent accumulation of sulfates in the system it is necessary to drain off a small part of the effluent after sulfur separation in the sulfur recovery unit. Sulfur Recovery Unit: A part of the effluent of the aerobic reactor is over a settling tank to remove the elemental sulfur. From the settling tank the sulfur sludge is denatured to a product with a dry solid percentage upped 70% by using Thickening Tank & Drying Bed. The sulfur quality can come to a purity of more than 90%. The instrumentation involved in the Bio scrubber unit includes the following:

A conductivity meter is provided to check the TDS level of the Bioreactor contents. When the TDS of the reactor contents exceeds the set value soft water is added to the reactor as a diluted. The Redox meter is provided to control the oxygen supply to the reactor. The oxygen supply to the reactor is decreased if the redox meter indicates high concentration of sulphates. A high sulphate concentration implies that, in the reactor, conversion of sulphide to sulphate is occurring. Elemental sulphur is the desired intermediate product, and therefore the oxygen supply should be prevented to prevent the formation of sulphates. The buffer tank is provided with automatic level control by means of a level switch which trips at low level the measuring pumps, which pump the reactor contents to the settling tank. The pH of the reactor contents is monitored using a pH meter. When the pH decreases below the set value the caustic pumps are stared to pump caustic from the caustic solution tank. The system is fully automated with respect to conductivity, pH and redox potential and associated controls.

Sludge Balancing Tank, T 112

A sludge balancing tank of size 8m (L)*4m (W)*3.13m (LD) is provided to receive the digested sludge from the digester. The TWL in the sludge balancing tank matches with that of digester. The sludge balancing tank has a capacity of 2 hours retention time based on the capacity of running centrifuges for Phase-I&II. The sludge-balancing tank is fitted with two agitators (AG 102 A/B) to keep the sludge in suspension and also provided with a telescopic pipe to allow the supernatant to flow back to the Distribution Chamber-1.

Sludge Dewatering System (Centrifuges)

Three numbers (2W+1S) centrifuges CTF 101 A/B/C, each of 25-m^3/h capacity are provided in a building for the dewatering of 6% digested sludge. The centrifuges are of solid bowl type. The dewatered sludge shall fall directly on to the waiting trailer, beneath the centrifuge platform.
Three (2W-1S) centrifuge feed pumps (CFP 101 A/B/C) of capacity 25 cum/hr. are provided to feed the digested sludge from sludge balancing tank to centrifuges. These pumps are housed at ground level, under the Sludge Balancing Tank. Two number (1W+1S) Polyelectrolyte dosing tanks (DT 101 A/B) are provided in the Centrifuge Building. Each tank is fitted with an agitator (AG 101 A/B). Three nos. (2W+1S) polyelectrolyte dosing pumps (DP 101 A/B/C), each of 500 l pH capacities are provided to dose 0.5% polyelectrolyte solution to centrifuge to improve the dewatering characteristics of the digested sludge.

Purpose

It is provided to separate or to dewater the digested sludge by dosing the dewatering the poly electrolyte

Supernatant and Filtrate Sump & Pump House

A supernatant and filtrate sump (S-104) of size 29.00 m (L)* 16.60(W)*2.40 m (LD) is provided to receive the supernatant from Thickener and centrate from centrifuge. The supernatant and centrate is pumped to the distribution chamber of primary clarifiers, by three (2W+1S) Supernatant and Filtrate Pumps, SP-104 A/B/C, each of capacity 110 m^3/h. the sump is provided with a level switch to trip the working pumps at low level with alarm.

Purpose

- For receiving the 100% centrate from the centrifuge and over flow from the thickener pump to the distribution chamber-I.

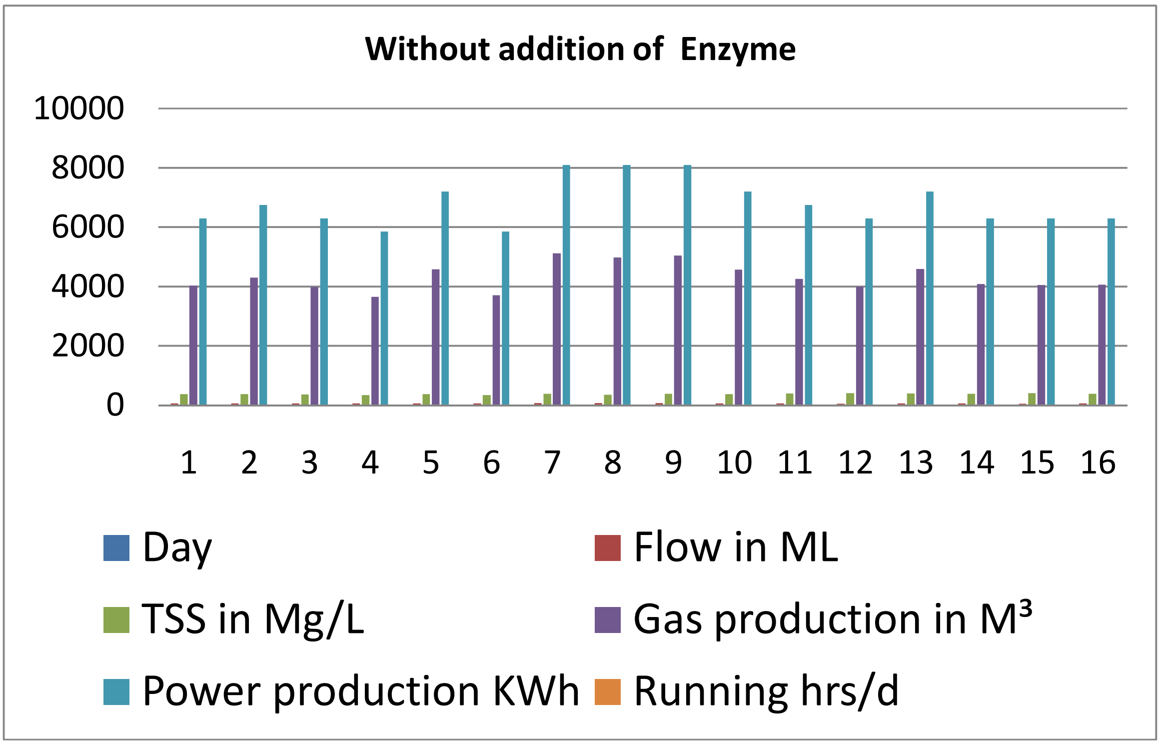
RESULTS AND DISCUSSION

The biogas is an environmental friendly source of energy. It is a by-product of anaerobic decomposition of organic matter, consists mainly of methane, carbon dioxide and trace amounts of ammonia, hydrogen sulfide and other gases. The present study was done in the last four months and the sampling was done seasonally from the sewage treatment plant in prungudi. Normally the biogas production is 0.9m^3 /kg without addition of Enzyme. The average rang of production of biogas is 4315m^3 /day and the power production is 6806 KWh/day. The below Table1 we mentioned the production of biogas and bioelectricity values.

Table1
Without addition of Enzyme

Day	Raw Sewge		Without addition of Bio-Enzyme		
	Flow in ML	TSS in Mg/L	Gas production in M^3	Power production KWh	Running hrs/d
1	59	380	4029	6300	14
2	63	380	4302	6750	15
3	60	370	3989	6300	14
4	58	350	3648	5850	13
5	68	375	4582	7200	16
6	60	345	3719	5850	13
7	73	390	5116	8100	18
8	77	360	4981	8100	18
9	72	390	5046	8100	18
10	67	380	4575	7200	16
11	60	395	4259	6750	15
12	55	405	4002	6300	14
13	64	400	4600	7200	16
14	58	392	4085	6300	14
15	55	410	4052	6300	14
16	58	390	4064	6300	14
Total	1007	6112	69049	108900	242
Average	63	382	4315	6806	15

Diagram 1
Analysis of TSS, Flow, Biogas production, Power production and Running hours



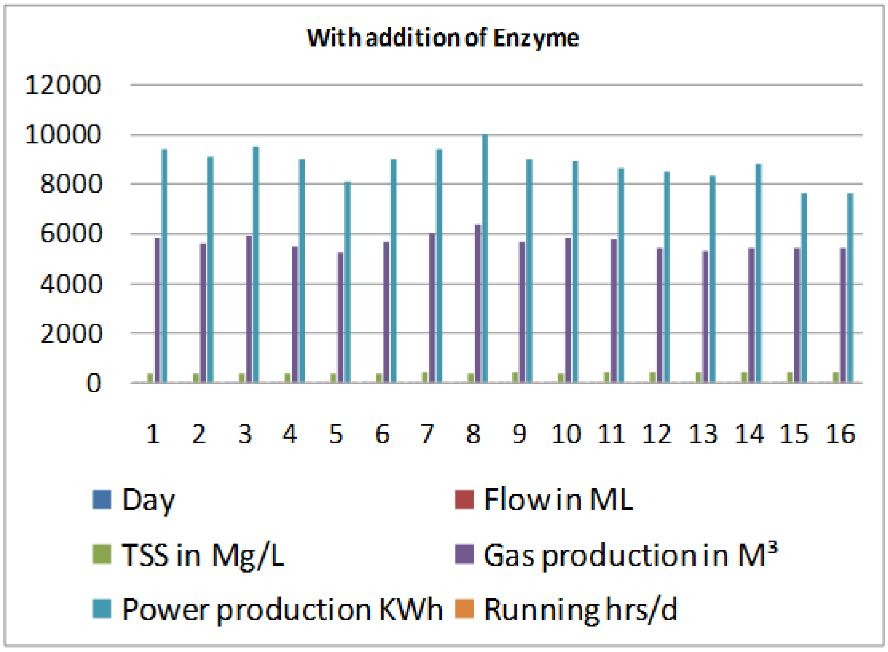
With Enzyme

Our Bio-Enzyme is having *Trehalose* it is specialized carbohydrate for developing growth factor *Arechea bacteria* which is sole responsible in the formation of Methane gas. Methane gas formation has been enhanced and consumption 18 to 20% less than we compare to regular bio-gas, by adding the Bio-Enzyme 0.18m^3 of Biogas is produced in this process. After addition of Bio-Enzyme the biogas production is 0.18m^3 /kg with addition of Enzyme. The average rang of production of biogas is 5633 m^3 /day and the power production is 8800 KWh /day.Table2 we mentioned the production of biogas and bioelectricity values.

Table 2
With addition of Enzyme

Day	Raw Sewge		With addition of Bio-Enzyme		
	Flow in ML	TSS in Mg/L	Gas production in M³	Power productio n KWh	Running hrs/d
1	59	380	5807	9400	21
2	63	380	5600	9100	20
3	60	370	5883	9500	21
4	58	350	5489	9000	20
5	68	375	5210	8100	18
6	60	345	5623	9000	20
7	73	390	6001	9400	21
8	77	360	6351	10000	23
9	72	390	5659	9000	20
10	67	380	5809	8900	20
11	60	395	5784	8600	19
12	55	405	5397	8500	19
13	64	400	5291	8300	18
14	58	392	5428	8800	19
15	55	410	5395	7600	17
16	58	390	5395	7600	19
Total	1007	6112	90122	140800	315
Average	63	382	5633	8800	20

Diagram 2
Analysis of TSS, Flow, Biogas production, Power production and Running hours



Comparison of with and without Enzymes

In this method the bio-enzyme has the capacity to increase the biogas production. The below table the both with and without addition of bio-enzyme data's are compared and finally we got the high production of biogas and power in the addition of bio-enzyme.

Table 3
Comparison of with and without Enzyme

Day	Raw Sewge		Without addition of Bio-Enzyme			With addition of Bio-Enzyme		
	Flow in ML	TSS in Mg/L	Gas production in M^3	Power production KWh	Running hrs/d	Gas production in M^3	Power production KWh	Running hrs/d
1	59	380	4029	6300	14	5807	9400	21
2	63	380	4302	6750	15	5600	9100	20
3	60	370	3989	6300	14	5883	9500	21
4	58	350	3648	5850	13	5489	9000	20
5	68	375	4582	7200	16	5210	8100	18
6	60	345	3719	5850	13	5623	9000	20
7	73	390	5116	8100	18	6001	9400	21
8	77	360	4981	8100	18	6351	10000	23
9	72	390	5046	8100	18	5659	9000	20
10	67	380	4575	7200	16	5809	8900	20
11	60	395	4259	6750	15	5784	8600	19
12	55	405	4002	6300	14	5397	8500	19
13	64	400	4600	7200	16	5291	8300	18
14	58	392	4085	6300	14	5428	8800	19
15	55	410	4052	6300	14	5395	7600	17
16	58	390	4064	6300	14	5395	7600	19
Total	1007	6112	69049	108900	242	90122	140800	315
Average	63	382	4315	6806	15	5633	8800	20

CONCLUSION

The biogas is an environmental friendly source of energy. It is a byproduct of anaerobic decomposition of organic matter consists mainly methane (CH_4), carbon dioxide (CO_2) and trace amounts of ammonia and other gases. The present study was done in the months of summer and the sampling was done in the sewage treatment plant. We used bio-enzyme inside the digester to increase the amount of biogas. After using bio-enzyme the average production rate of biogas is 5633m3. To produced the electricity the average amount of biogas consumed was 8800m^3 KWh/ day. The total amount of Biogas production for 16 day is 90122m^3 and the Power production is 140800 KWh.

REFERENCES

1. Kashyap, D.R., Dadhich, K.S., Sharma, S.K., 2003. Biomethanation under psychrophilic conditions: a review.Bioresour.Technol.87 , 147–153(.2003)
2. Lui H, Ramnarayanan R. Logan BE Production of electricity during wastewater treatment using a single chamber microbial fuel cell. Env Sc Tech 38:2281-2285.(2004)
3. Min B, Logan BE Continuous electricity generation from domestic wastewater and organic substrates in a flat plate microbial fuel cell. Env Sc Tech 38:5809-5814. (2004)
4. Tiehm A, Nickel K, Zellhorn M et al Ultrasonic waste activated sludge

disintergration for improving anaerobic stabilization. Water Res 35(8):2003–2009. (2001)

5. Ra CS, Lo KV, Shin JS et al Biological nutrient removal with an internal organic carbon source in piggery wastewater treatment. Water Res 34:965–973. (2001)
6. Sevrin-Reyssac J Biotreatment of swine manure by production of aquatic valuable biomasses. Agric Ecosyst Environ 68:177–186.(1998)
7. Van Ginkel S, Oh SE, Logan BE Biohydrogen gas production from food processing and domestic wastewaters. Int J Hydrogen Ener 39(16):3819–3826.(2005)
8. Maekawa T, Liao CM, Feng XD Nitrogen and phosphorus removal for swine wastewater using intermittent aeration batch reactor followed by ammonium crystallization process. Water Res 29:2643–2650. (1995)
9. Parawira W, Murto M, Read JS, Mattiasson B. Profile of hydrolases and biogas production during two-stage mesophilic anaerobic digestion of solid potato waste. Process Biochemistry. 40 (9), 2945-2952. (2005).
10. Garcia-Heras JL. Reactor sizing, process kinetics and modeling of anaerobic digestion of complex wastes. Ed. Mata-Alvarez, Biomethanaization of the organic fraction of municipal solid wastes, IWA, UK. pp. 21-58.
11. Schink B. Energetics of syntrophic cooperation in methanogenic degradation. Microbiology and Molecular Biology Reviews. (1997).61 (2), 262-280.
12. Klass DL. Methane from anaerobic fermentation. Science223 (4640), 1021-1028. (1984)
13. Kotsyurbenko OR. Trophic interactions in the methanogenic microbial community of low-temperature terrestrial ecosystems. FEMS Microbial Ecology. 53 (1), 3-13. (2005).
14. Petersen SP, Ahring BK. Acetate oxidation in thermophilic anaerobic sewage sludge digester: the importance of nonaceticlastic methanogenesis of acetate. FEMS Microbial Ecology. 86, 149-158.(1991).