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Enhancing bio-gas production from kitchen waste using BSA-iron oxide nanoparticles in miniature level bio-reactor

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ABSTRACT

Purpose: This study focuses on increasing production of biogas as an alternative energy from biodegradable wastes (BWs) using BSA coated iron oxides nanoparticles, in view of solving waste management at household level. Many attempts have been performed in order to increase biogas production, including thermal pre-treatment of organic waste, but all of them present limited industrial applications. Iron has been shown to enhance anaerobic digestion, but there are severe drawbacks for introducing the metal ion in an anaerobic closed reactor.

Design/methodology/approach: Process for the production of biogas from biodegradable material which comprises the steps of: (a) adding the biodegradable material to the Bio-reactor,(b) inoculating the microorganisms in the digester,(c) synthesis iron oxides and BSA powder coated on the particles (d) adding a colloidal solution of surface-modified BSA-iron oxide nanoparticles to the reactor; (e) providing anaerobic conditions; (f) carrying out the anaerobic digestion; and (g) collecting the biogas, wherein the steps (a), (b) and (c) can be carried out in any order. It also comprises the use of BSA-iron oxide nanoparticles capable of supplying Fe ions to the media for biogas production in anaerobic conditions and in the presence of Fe ions in the media.

Keywords: BSA-Bovine serum albumin; Iron oxides; Bio-digester; Kitchen waste

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CLEANER PRODUCTION AND BIOTECHNOLOGY

1. Introduction

Biogas is a sustainable alternative source of energy, for example. It can be used as a low cost fuel, but to date there is still a lack of efficiency in its production. Energy is the fundamental necessity for human life for physiological, mechanical, and economic development. Biogas is produced from the anaerobic digestion of organic matter such as animal, sewage, and municipal solid waste. The process produces methane and carbon dioxide. After processing of biogas to required standards of purity, it becomes a renewable substitute for natural gas and can be used to fuel natural gas vehicles, helping to replace fossil fuels. Compact biogas plant is a new biogas technology. It is a floating cylindrical tank biogas plant. The biodegradable kitchen wastes are used as feeding materials. The main objective of the study is enhancing biogas production as an alternative energy from anaerobic bio digestion of biodegradable household wastes using BSA-Iron oxides nanoparticles.

Study site

The study was carried out in MEPCO schlenk engineering college at Sivakasi of Virudhunaga rdistrict.

2. Experimental

2.1. Designing and fabrication of digester

The bio-reactor (Fig. 1) and gal holder was designed based on the following Specification: Volume of bioreactor 0.12 m^3, 41.2 cm diameter, 72.5 cm height, 1.5 kg weight [17].

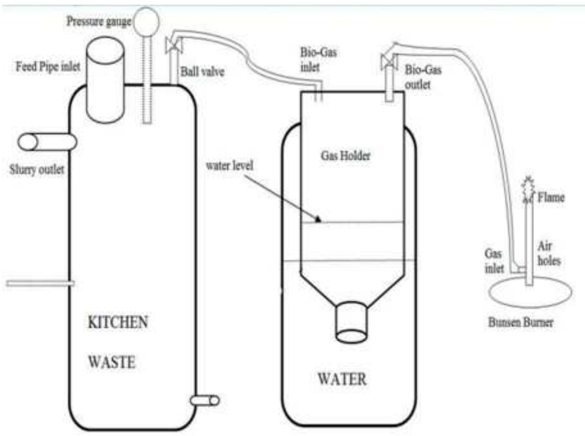

Fig. 1 Model of bio-reactor

2.2. Collection of materials

The feed materials for the biogas plant such as meats, vegetable waste, food waste from hostels, fruits, teabags, etc., were collected from different sources (Fig. 2). Cow dung and kitchen wastes were collected from nearby villages.

2.3. Materials

The chemicals used in this work were $FeCl_2.4H_2O$, $FeCl_3.6H_2O$, ammonium hydroxide; BSA (Bovine Serum Albumin), distilled water was used for preparing the solutions after deoxygenating with dry N_2.

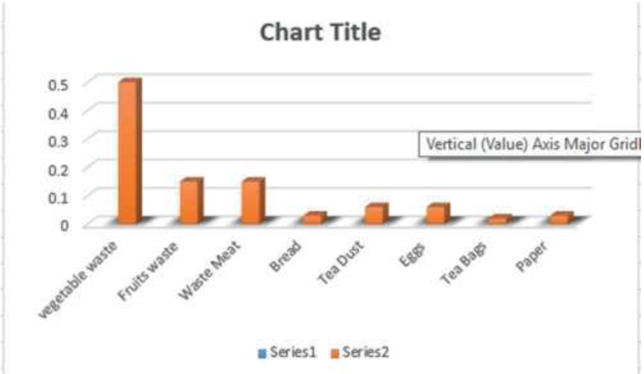

Fig. 2. Composition of waste [4]

2.4. Preparation of Fe_2O_3 nanoparticles

4 g of iron nitrate is added and continuously stirred with 50 ml of Distilled water. Then, citric acid solution is added into the iron nitrate and 100 ml solution is made.NH_3 solution is continuously added drop by drop into 100 ml Solution (citric acid & iron nitrate solution) until the solution occur dark blue colour (pH: 10) pH is measured using pH meter. The solution is heated in 80°C by using Hhot plate until it become red solution. Then, red solution is calcineted in furnace at 700ºC-800ºC up to 2 hours [6].

2.5. Preparation of Fe_3O_4 nanoparticles

Solution 1 – 0.1117 g of Iron powder is weighed by Digital balance concentrated 5 ml (HCl) Hydrochloric Acid is added into Iron powder. Iron powder and Hydrochloric acid (HCl) are mixed together in a 100 ml beaker.

Solution 2 – 1.08 g of Iron chloride powder is weighed by digital balance.4 ml distilled water is added into the Iron chloride powder. Iron chloride powder and distilled water are mixed together in a 100 ml beaker [6].

Solution 1 – (iron powder and HCl) is heated by using hot plate in 70ºC, until it become a green colour powder then, it is cooled for 2 hrs. After 2 hrs, the green colour Powder is dissolved by adding 2 ml distilled water. Immediately the magnetic beed is added to the solution and placed on the magnetic stirrer. Then, Solution 2 – (Iron Chloride solution) is continuously added drop by drop into the Constant magnetic stirring iron powder solution in equal intervals of 5 min. In 50 ml NH_3 (Ammonia) is added for every 10 min until it became Dark Black.

2.6. Synthesize BSA-coated iron oxides nanoparticles

Synthesized iron oxides nanoparticles separated and washed several times with deionized water and once with ethanol. BSA coating process is shown in Fig. 3.

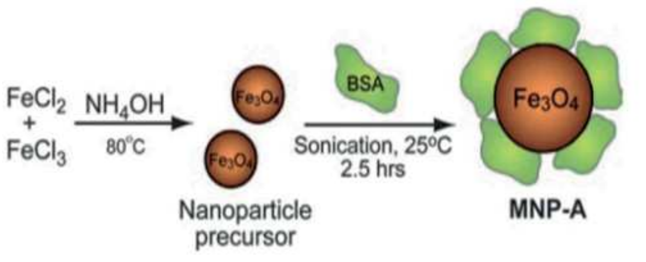

Fig. 3. BSA coating process

Solution 1 **–** 0.250 mg of Bovine Serum Albumin protein powder dissolved in 20 ml of deionized water. Immediately the magnetic beed is added into the solution and placed on the magnetic stirrer for 10 min.

Solution 2 **–** Synthesized iron oxide Nano Particles are dipped into NaOH Solution, and 20 ml of distilled water. The magnetic beed is added to the solution and placed on the magnetic stirrer for 15 min. Iron oxide solution is added into the BSA solution.

After 3 hours of sonication of iron oxides nanoparticles to be separated from remaining Bovine Serum Albumin Solution with help of Ferro magnate. After sonication process, the iron oxides are washed with deionised water. The process should be repeated 3 or 5 times and particles separated from water by Ferro magnate placed bottom of beaker. The semi-liquid solution dried until it become a powder form, finally Brown colour BSA coated Nanoparticles are obtained [9].

2.7. Laboratory analysis

The physico-chemical parameters such as total solid, volatile solid, pH, organic matter, were determined at the laboratory [2].

2.8. Measurement of temperature

Temperature of the bio digester was measured using laboratory thermometer [2].

2.9. Determination of methane content

The methane (CH_4) and carbon-dioxide (CO_2) in the produced biogas determined by Gas Analyzer Gas Board-3200P [2].

2.10. Measurement of volume of gas

The produced biogas volume was determined by measuring the height of the gas holder tank (20 litre water tank) at an interval days [2].

3. Result and discussions

3.1. Fourier transform infrared spectroscopy

FTIR is a type of spectroscopy that uses infrared radiation to record molecule moment via computer based programs. These three diagrams are complying with standard. Fig. 4 and Fig. 5 are respectively pure BSA and nano particles. The BSA-iron oxides nanoparticles are verified by Fig. 6 [10].

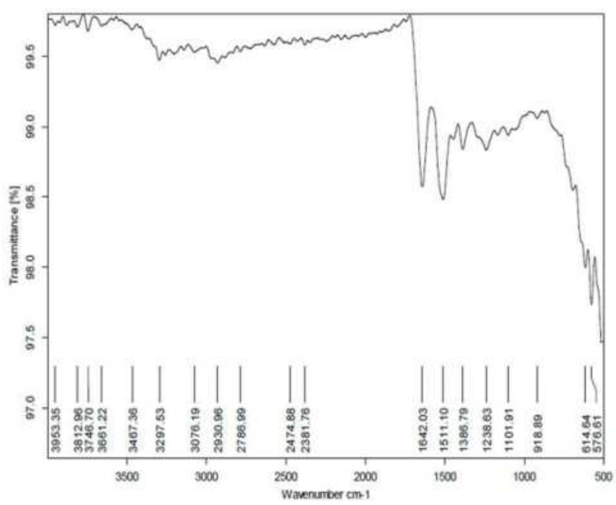

Fig. 4. FTIR result of pure BSA

3.2. Pl spectrum of BSA coated Fe_3O_4 magnetic nanoparticles

Photoluminescence is spontaneous light emission from particles under optical excitation. The excitation energy and intensity are chosen to probe different places and excitation concentrations in the sample. PL investigations can be used to characterize a variety of particles parameters [10] (Fig. 7).

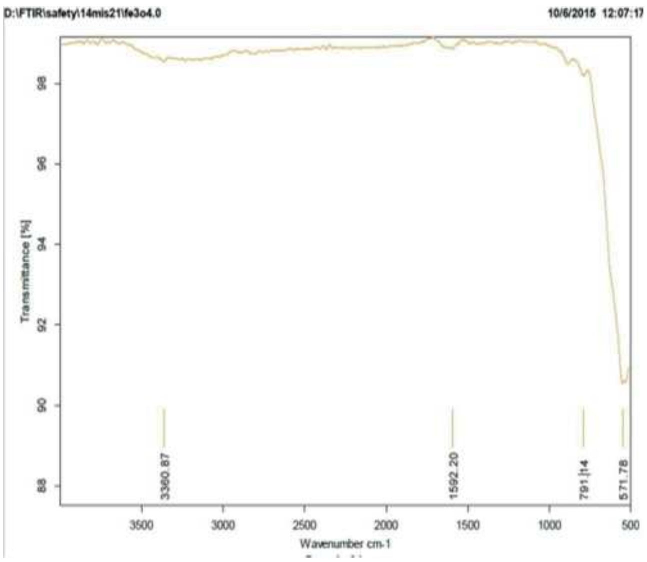

Fig. 5. FTIR result of pure Fe_3O_4 nanoparticles

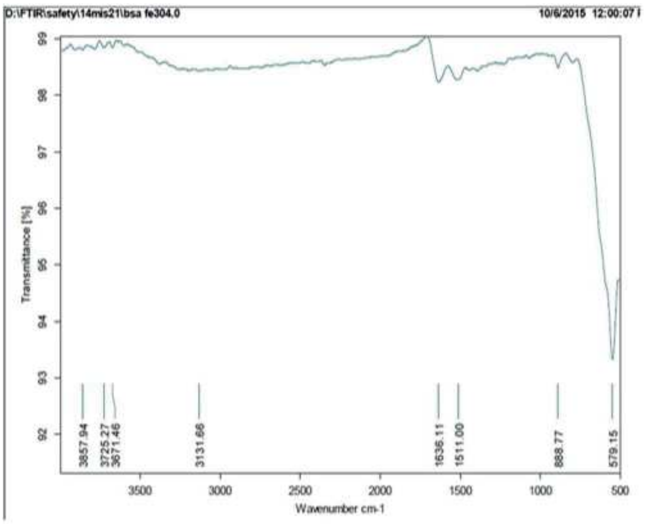

Fig. 6. FTIR result of BSA coated Fe_3O_4 nanoparticles

3.3. Samples of Fe_3O_4 & BSA core-shell nanoparticles prepared under different reaction conditions and their measurements

Fe_3O_4 = 0.10 g and stirring = 700 rpm for each reaction Samples. Different amount of Bovine Serum Albumin (BSA) protein powder was added into the iron oxides solution for Coating process. BSA content of iron oxides Nanoparticles determined by following Table 1 [8].

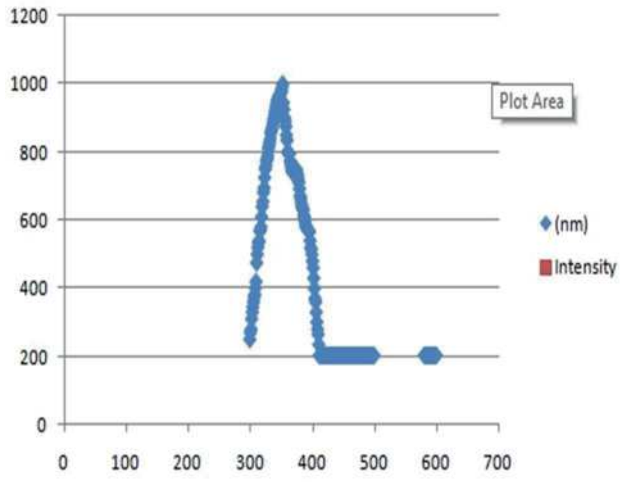

Fig. 7. PL result of BSA coated $Fe_3 O_4$ nanoparticles

Table 1.
Different reaction condition of Fe_3O_4&BSA

No.	BSA, g	pH	Content of BSA %
1	0.04	6.3	22.99
2	0.06	6.3	23.89
3	0.06	6.3	30.24
4	0.06	6.3	30.37
5	0.06	6.3	12.50
6	0.06	6.8	21.47
7	0.08	6.3	37.83
8	0.12	6.3	37.98
9	0.16	6.3	31.80
10	0.20	6.3	37.80

3.4. SEM images of iron oxides

The morphology and size, shape of the synthesized particles were investigated using scan electron microscopic. The SEM photograph of the prepared iron oxides nanoparticles are shown in Figure 8. These similar to the typical SEM images of uniform nanoparticles Fig. 8 are corresponding to the SEM images of magnetite NP prepared with BSA. It can be reduced from Fig. 9. The distribution of iron oxide nanoparticle size is very narrow. The mean diameter of NPs is less than 100nm, which was bigger than the naked nanoparticles. The size was demonstrated that the BSA was coated on nanoparticles successfully [10].

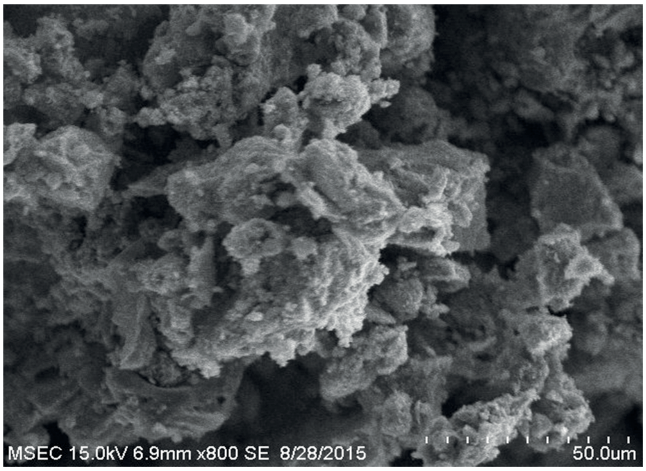

Fig. 8. SEM result Fe_3O_4 nanoparticles

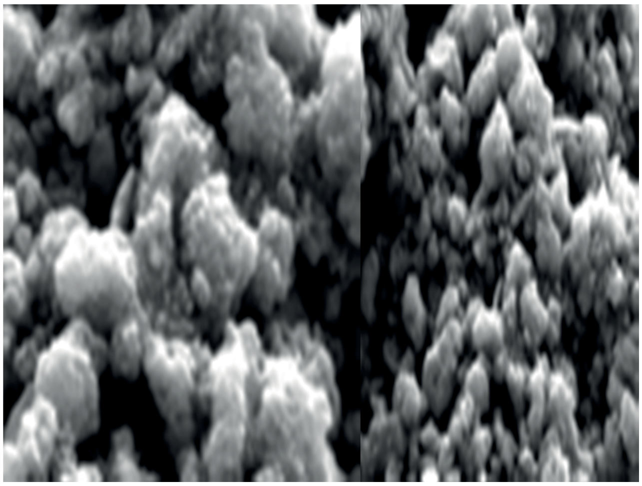

Fig. 9. SEM result of BSA coated Fe_3O_4 nanoparticles

3.5. pH test

The pH worth of the bio digester is a crucial indicator of the performance and therefore the stability of an anaerobic digester. During a well-balanced anaerobic digestion method, the majority product of a metabolic stage area unit endlessly converted into successive breaking down product with none vital accumulation of intermediate products like completely different fatty acids which might cause a pH drop. Most anaerobic microorganism together with alkane forming microorganism perform during a pH vary of 6.5 to 7.5, however optimally at a pH of 6.8 to 7.6, and therefore the rate of alkane production might decrease if the pH is less than 6.3 or more than 7.8 (Fig. 10) [3].

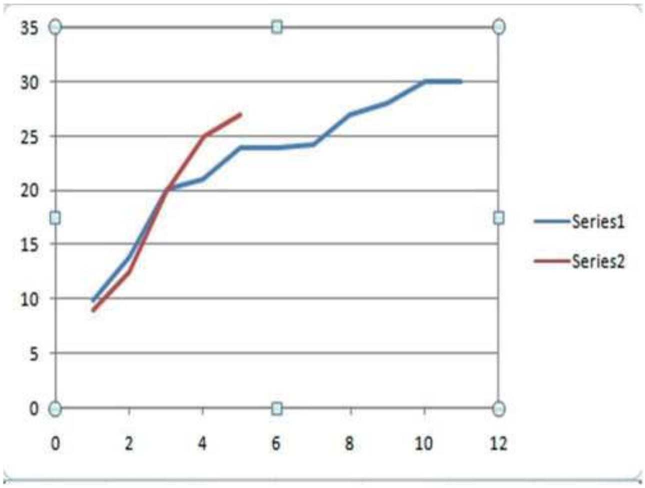

Fig. 10. pH test

3.6. Temperature measurement

Temperature is vital parameters in anaerobic digestion. It determines the speed of anaerobic degradation processes significantly the rates of chemical reaction and methanogenesis (Fig. 11) [16].

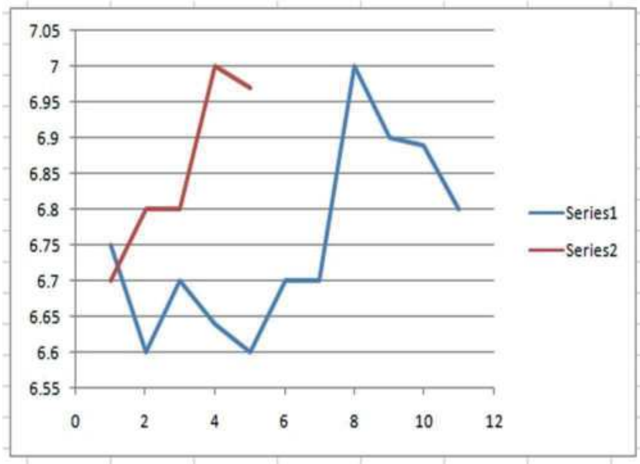

Fig. 11. Temperature measurement

3.7. Total solid test

The sample, approximately 10 gm is taken and poured in foil plate and dried to a constant weight at about 105°C in furnace (Table 2) [4].

TS % = (Final weight/Initial weight) * 100.

Table 2.
Total solids

Day	Digested slurry, g Conventional	Digested slurry, g BSA-Iron Oxides
1	8	8.1
2	8	8.1
3	7.9	7.3
4	7.7	7.0
5	7.1	6.9
6	6.5	
7	6.3	
8	6.3	
9	6.2	
10	6.0	
11	6.0	

3.8. VFA-volatile fatty acid

pH value of the sample is recorded (Table 3). The sample is titrated slowly with 0.1 N sulphuric acid until pH 5.0 is obtained. The added volume A1 [ml] of the titrant is recorded. Again, more acid is slowly added, until pH value of sample is reached 4.3. The volume A2 [ml] of the added titrant is again recorded. And the step is repeated until pH 4. 0 is reached, and the volume A3 [ml] of added titrant recorded once more.

Sample is constantly mixed and titrant is added right from the start. (Alk-Alkalinity)

Alk = A * N * 1000 / SV (A=A1+A2)

VFA = (131340 *N * B/ 20) - (3.08 * Alk) - 10.9

Table 3.
Volatile solid test

Day	Digested slurry, mg/l Conventional	Digested slurry, mg/l BSA-Iron oxides
1	1968.7	1956.7
2	1837.2	1853.2
3	1802	1750.9
4	1750.3	2015.3
5	2012.5	2808.5
6	2187.6	
7	2805	
8	2637.4	
9	2345.1	
10	2235.1	
11	2177.5	

3.9. A/TIC-ratio

The stability of the process inside the digester, expresses the ratio between Volatile Fatty Acids and buffer capacity (alkalinity) [4].

$$\frac{\text{A[mg/l]} = \text{VFA [mg/l]}}{TIC[mg/l] = Alkalinity\ [mg/l]}$$

3.10. Bio-gas production conventional method

- Cow dung + Water = 4kg + 4 L
- Kitchen Waste + Water = 6kg + 6 L
- Total volume of Digester = 0.12 m^3
- Total volume of cylindrical water can =0.02 m^3
- Digestion of days = 10 days
- Volume of Water can =>$V = \pi r^2 h$

Volume of produced gas was determined by tank holder level = 0.004775 m^3

3.11. Bio-gas production BSA method

- Cow dung + Water +BSA-Iron oxides = 4kg + 4 L + 4g
- Kitchen Waste + Water + BSA-Iron oxides = 6kg + 6 L + 6g
- BSA-Iron oxides Concentration in the digester 0.5 between 1 mg/ml => 1 g/l
- Total volume of Digester = 0.1 2m^3
- Total volume of cylindrical water can = 0.02 m^3
- Digestion Of days = 5 days
- Volume of Water can =>$V = \pi r^2 h$

Volume of produced gas was determined by tank holder level = 0.004088 m^3

In conventional process it takes around 10 days, to produce the biogas of volume 0.004775 m^3. Instead, using the BSA- Iron oxide, it takes only 5 days to produce 0.004088 m^3 of biogas. BSA- Iron oxide nano particles increases the microbial digestion so degradation takes place very fast (Table 4, Fig. 12). The time taken to produce bio gas is low when compared with conventional method.

Table 4.
Specifications

Method	Conventional	BSA-Iron oxides
Cow dung	4 kg	4 kg
Kitchen Waste	6 kg	6 kg
Water	10 L	10 L
BSA-Iron oxides	-	10 g
Height of gas holder	8.5	7.7
Days	10	5
Produced bio gas	0.004775 m^3	0.004088 m^3

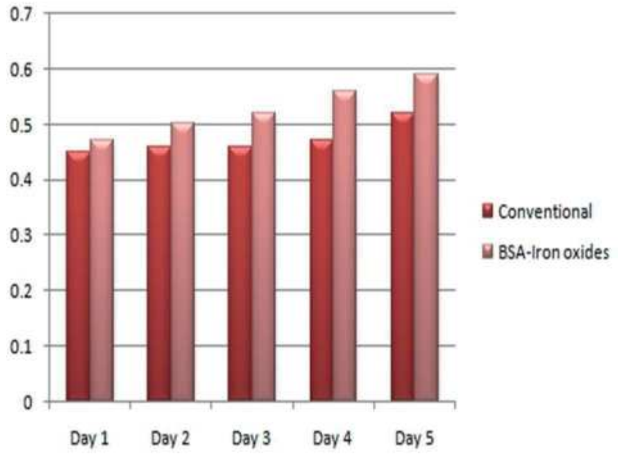

Fig. 12. The tank holder move to upward direction based upon the gas production rate

4. Conclusions

It is found that the use of iron oxide nanoparticles in the process for the production of biogas, from biodegradable material via an anaerobic digestion results in an increase of biogas production. The degradation time of kitchen waste is reduced and increased biogas production with help of Bovine Serum Albumin protein powder coated iron oxides nano particles. The process is advantageous since an increase in the efficiency results in a more cost- efficient process. A liquid residue rich in nitrogen and phosphates formed during anaerobic digestion is suitable to use as organic fertilizer. To treat organic wastes, anaerobic digestion is the most possible technique. During bio digester process, slurry is produced which can be used as a fertilizer in agriculture.

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