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Enhanced biogas production from fecal sludge by iron metal supplementation: iron enriched fertiliser as a byproduct

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Abstract. Iron has strong influence on microbial metabolism and can inhibit activity of microbes in cases of excessive concentrations or of low bioavailability of nutrients**.** Addition of iron fulfils the deficiency of seven enzymes provided by eight microorganisms. These enzymes are very essential for the microbial activity during anaerobic digestion for enhanced methane production. In this study the anaerobic digestion of fecal sludge was conducted in the presence of iron powder (Fe) as a trace element and the temperature was maintained at mesophilic range i.e. 35°C. For the correction of C: N ratio, co-digestion of fecal sludge and kitchen waste was done. The gas produced was measured by water displacement method. Biogas production from human feces as substrate when supplemented with different concentration of iron powder resulted with improved amount of methane as that from the fecal sludge in the control. Results showed that the production of methane was improved to 53.11 % and 64.74 % in the presence of iron powder, respectively at the dose rate of 0.25 g Fe and 0.5 g Fe per 200 g sludge. The increase in methane yield from Co-digestion was found to be 76.27 % as compared to that of fecal sludge in control.

1. Introduction

The world population is growing and consequently the demand for food is growing. Agriculture plays an important role for food production to supply people with adequate nutrients and nourishments. Excreta are a low-cost fertilizer which consists of all nutrients that are required for a crop to grow and is available where people live (World Health Organization, 2006). From different research, it has been proved that organic fertilizer made from fecal sludge is a quality fertilizer. Fertilizer value of organic fertilizer is more beneficial than chemical fertilisers. Organic fertilizer increases soil health and is explained by at least three interrelated factors: nitrogen is in a slow release organic form preventing leaching or runoff; high organic carbon content provides an instant energy source, which boosts soil microbial activity; and organic matter improves poor soil physical conditions resulting from topsoil loss and compaction [1]. On the other hand, chemical fertilisers are known for causing a gradual decline in soil fertility and environmental pollution through nutrient leaching and heavy metal pollution [2]. Due to the challenges associated with the use of inorganic fertilizers, the nutrient rich digestate from the anaerobic digestion process can become a viable alternative for soil amendment [3]. Anaerobic digestion consist a series of microbiological reactions and it must be ensured that the microbial community under the process is as active as possible and performs optimally. Several important factors influence microbial growth and activity including ideal conditions of pH, temperature, redox potential, carbonaceous substrates, macronutrients such as nitrogen, phosphorus, potassium, calcium, magnesium and sulphur; and micronutrients such as cobalt, copper, fluorine, iodine, iron, manganese and zinc collectively called trace elements (TE) [4]. In biochemistry, a trace element is an element that is required in very minute quantities to improve the proper growth, development, and physiology of the organism. The balanced availability of various nutrients which

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provide ideal growth conditions during anaerobic digestion is essential for well- working anaerobic digesters. Limitations to any of those factors may disturb the activity of specific groups of microorganisms and it may lead to impaired performance of the digester [4]. TE, such as iron has a strong influence on microbial metabolism and can inhibit activity in cases of excessive concentrations or of low bioavailability.

Fecal sludge contains pathogenic microorganisms which make it environmental and health hazards. Pathogens can be transferred to humans through the skin or via consumption of water and infected food that have been in contact with fecal sludge. At human exposure, the pathogens may cause spreading of fatal diseases such as diarrhoea and cholera [5]. To prevent environmental hazard and protect public health, fecal sludge treatment prior to reuse is required. The organic matter in the sludge is readily degradable by anaerobic processes, carried out by microorganisms at favourable conditions, which enables stabilisation of the sludge. Stabilisation of sludge by microorganisms destroys most pathogens, reduces the volume of sludge and may also improve the dewaterability of the sludge [6]. The study focuses on the yield of biogas from human feces supplemented with iron powder. The purpose for iron powder supplementation is to increase the concentration of deficient iron above the limiting level and improve the microbial activity, leading to enhanced biogas production. Among many trace metals, the use of micro iron powder filling is implemented in the study as addition of iron fulfil the deficiency of various enzymes provided by various microorganisms [7]. Iron is a necessary element for plant's growth and since the formation of chlorophyll is not possible without the presence of iron, therefore plants deficiency or deactivation of iron show with chlorosis of their leaves. Also, iron is cost effective, less harmful to the health of the researcher and when discarded to the environment.

The performance of biogas plants is affected by many factors among which temperature is one of the most important factors impacting on the digester's biological activity and hence biogas yield [8]. The study focuses on the biogas yield from iron enriched human feces at 35±2°C. The temperature 35±2°C is chosen for the experiment because the methane- producing bacteria operates most efficiently at mesophilic range of temperature (30.0 – 40.0ºC) in comparison to psychrophilic range of temperature. Also, this is the mean optimum temperature which degrades the disease causing pathogens when exposed to the environment. Since the human feces have high nitrogen content it may not yield good volume of methane [9]. Thus to achieve desirable yield of biogas, kitchen waste is used as co-substrate for the co-digestion process. Kitchen waste has high C: N ratio (29) as compared to human feces (7) and also it is the most common material available with very less effort [10].

2. Materials and methods

2.1. Substrates and micro iron powder

Freshly deposited human feces were collected in 1000 ml airtight plastic bottles from Kathmandu University Girls Hostel (KUGHS) and Kathmandu University Staff Quarter which is situated at Dhulikhel. The collected sample was brought to the Biogas Laboratory provided by Department of Environment Science and Engineering (DESE) and the lab work was performed immediately.

For co-digestion, kitchen waste were collected in 1000 ml airtight plastic bottles from Kathmandu University Canteen and brought to the laboratory for further lab work. Safety measures like using mask, gloves, and apron were used during the collection process.

The sludge underwent physical analysis which consisted into the determination of Total Solids (TS) and Volatile Solids (VS). Ferrous Iron (Fe) powder (purity > 98% and diameter 0.2 mm) was purchased from Laboratory Trade Concern Pvt. Ltd, Kathmandu for the study.

2.2. Physical analysis

Here, Total Solids (TS) and Volatile Solids (VS) were calculated. Calculations of TS and VS of the substrate were done by using standard procedure of APHA (2013).

For total solids, a known amount of sample was transferred into weighed crucible and dried at 105°C for 24 hours. And for volatile solids, the dried sample obtained after TS estimation was ignited in a muffle furnace at 550°C for 2 hours. The weight lost on ignition represents the volatile solids.

The formula for the calculation of the total solids and volatile solids is given below:

1) Total-solids: (Weight after 105 °C-Crucible weight)/ (Sample weight) * 100%

2) Volatile-solids: (Weight after 105 °C-Weight after 550°C)/ (Sample weight) * 100 %

2.3. Experimental setup for biogas and methane measuring

500 ml of glass bottle were modified to make anaerobic digester for an experiment on biogas generation from human feces. The cap of the bottle was modified by replacing it with a rubber cork in which a hole was drilled in order to fit glass pipe and it was fixed with M-seal by attaching it to PVC pipe. Inside the digester, a pipe for gas outlet pipe was made shorter and was above the digesters sludge level. PVC pipe is also attached with another glass bottle which consists of a 1M NaOH solution. The cap of the bottle was modified by boring two holes in order to fit inlet and outlet PVC pipe and it was fixed with M-seal. Inside the bottle, a pipe for gas outlet pipe was made shorter and was above the NaOH solution level whereas another pipe was extended to bottom level for the absorption of carbon dioxide along with other gases.

The yield biogas was first passed through 1M NaOH solution, which absorbs carbon dioxide (CO_2) gas and the remaining gases are passed into another vessel containing water. Due to pressure difference of methane and others very few gases displace water into the water tub. Measurement of displaced water is done in a measuring cylinder which is nearly equal to the volume of methane gas .The chemical reactions involved in the removal of CO_2 by sodium hydroxide (NaOH) solution are: [11]

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O \quad (1)$$

$$Na_2CO_3 + CO_2 + H_2O \leftrightarrow 2NaHCO_3\downarrow \quad (2)$$

$NaHCO_3$ is in precipitate form which can be removed from the solution.

The presence of NaOH in the solution is checked time to time by using phenolphthalein to assure removal of CO_2. When, one or two drops of phenolphthalein is added, if pink colour disappears it indicates NaOH is still present.

2.4 Experimental design

Four batches experiment triplicate of each was set where fecal sludge is enriched with iron powder, (purity > 98% and diameter 0.2 mm) to different concentrations A (200 g sludge+0 g Fe); B (200 g sludge+0.25 g Fe); C (200 g sludge+0.5g Fe) and D (100g sludge + 100 g KW + 0.25g Fe). Well mixed sample was diluted with distilled water to 15% dry matter (DM) and homogenized manually. 500 ml glass bottles were used for experiment. Bottle was air tight with the cork and a hole was made in the cork so that it will be easy to insert the pipe into the bottle.

The potential for biogas production varies with the concentration of Fe. For the co-digestion of fecal sludge in the presence of iron powder, kitchen wastes (KW) were used. The temperature of the water bath was maintained at 35°C where the substrate was kept. Finally, the gas produced was measured daily using water displacement method.



Figure 1. Experimental Setup for Bio Methane Potential Test

3. Results and discussion

3.1. Physical analysis

For the physical analysis TS and VS calculation of the substrate was done using the standard procedure of APHA 2013.

Table 1. TS and VS of substrates

S.N	Substrates	TS(%)	VS(% of TS)
1.	Fecal Sludge	78.49	63.0
2.	Kitchen Waste	19.9	90.2

The volatile solids can be used as a measurement of sludge stabilisation, as the volatile solids are composed of readily degradable organic matter [12].

3.2 Experimental analysis

From the cumulative methane yield graph (Figure. 2.), we can see that the volume of gas produced from the digester D is maximum among the conditions conducted in this research. The methane yield from digester C is double as that of digester A.

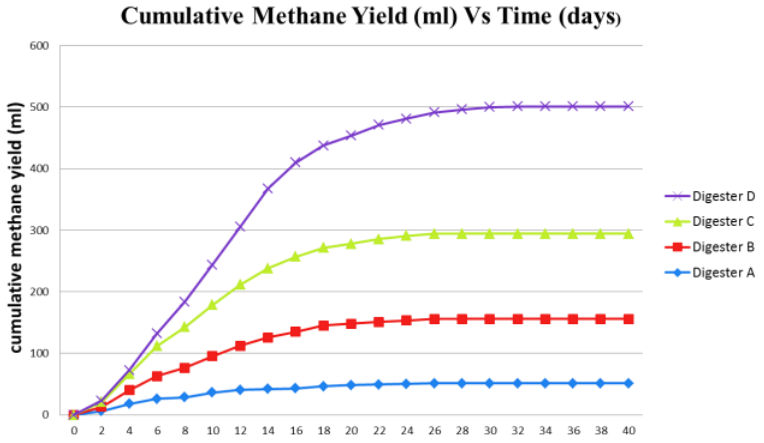


Figure. 2. Cumulative Methane Yield from different digesters.

The chemical effect of iron on methane production is further explained by following equations: [9]

$$8H^{+} + 4Fe^{0} + CO_2 \rightarrow CH_4 + 4Fe^{2+} + 2H_2O \quad (3)$$

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \quad (4)$$

$$4H_2 + 2CO_2 \rightarrow CH_3COO^- + H^+ + 2H_2O \quad (5)$$

$$CH_3COO^- + H^+ \rightarrow CH_4 + CO_2 \quad (6)$$

The enhanced performance of the anaerobic digestion in the presence of iron powder can be explained by the enrichment of bacterial activity in the environment due to the electron released in the bio- digesters by the electron donors ($Fe^0 \rightarrow Fe^{2+} + 2e$). There is imminent conversion of part of the produced CO_2 to CH_4 via the equation (3). Consequently, the volume of produced methane is increased while CO_2 production is considerably reduced. Furthermore, a part of produced CO_2 is converted into CH_4 by fixing H_2 (which is produced during Fe corrosion) as showed in equation (4). The process of the reaction between CO_2 and H_2 is passed by an intermediary to methane, which is further converted into methane (equation (5) and (6)) [9]. The methane yield from digester D is double as that of digester B and triple as that of digester A. Anaerobic digestion with the addition of co- substrates has been considered to reduce process limitations and improve methane yields [12]. Fecal sludge in control has very less nitrogen content and adding co substrate with higher C:N ratio accelerates the rate of gas production. Kitchen waste has 25.5 C:N ratio which is triple the C:N ratio of Fecal sludge. Supplementation of 0.25 g of iron powder balances the limited and excessive bio nutrients in the digester which consequently enhances the biogas production. Though it does not do much harm but iron is not an environmental metal of concern. So, to avoid iron contamination in the environment, least amount of iron powder (0.25 grams) was used along with co digestion. This investigation of co-digestion of fecal sludge and kitchen waste, in the presence of 0.25 grams of iron powder resulted in maximum yield of methane among the conditions conducted in this research.

4. Conclusion

The experiment carried out in small 500 ml bottle used as digester fed with human feces as substrate, kitchen waste as co-substrate and iron powder as trace metal in laboratory, co-digestion of fecal sludge and kitchen waste with an addition of 0.25 g of iron powder was found to produce the greatest amount of gas followed by fecal sludge with 0.5 g of iron powder, fecal sludge with 0.25 g of iron powder and fecal sludge respectively at 35℃. From the results of this study, the role of trace metal (Fe) on human feces is much appreciated with enhanced biogas yield. It appeared that the anaerobic digestion of human feces alone does not yield good methane as compared to that of iron supplemented human feces. The co-digestion is an effective way to maximize the gas production with prolonged period of production and improved digester performance. It has been found that the fecal sludge codigested with kitchen waste in the presence of iron powder have high potential to yield more gas. The outcome of this research has given a clear direction for the energy recovery and using the by-products as fertilisers. The digested sludge in dry and granular form can be safely used as organic fertiliser.

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