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Ratio Optimization for Biogas Production from Agricultural Waste Co-Digested with Sewage Sludge

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ABSTRACT
This paper describes the anaerobic biochemical methane potential (BMP) of agricultural waste, co-digested with sewage treatment plant (STP) sludge as an alternative renewable energy source coupled with an efficient waste management solutions. The anaerobic co-digestion mixing ratio of agricultural waste, with STP sludge and anaerobic seed sudge was optimized to maximize the biogas and methane yield and to minimize the ammonia toxicity in methanogenesis process. The ratios (agricultural waste, STP sludge and seed sludge) used were 1:2:1, 2:1:1, 3:1:1 and 1:3:1. The optimization of different ratios and the impact of Chemical Oxygen Demand (COD), Volatile Fatty Acids (VFA), Ammonia and Alkalinity on biogas production were monitored using BMP bottling method. The ratio 1:2:1 was found to have good biogas production with maximum of 489 ml/day with subsequent changes in process monitoring parameters. This will help to design the large scale plant with respect to the waste handled in the anaerobic digestion process.

Keywords
Biochemical Methane Potential, methanogenesis, seed sludge.

1. INTRODUCTION
Energy is the key input for socio-economic development of any Nation. The fast industrialization and rapid urbanization besides mechanized farming have generated a high demand of energy in all forms i.e. thermal, mechanical and electrical. To meet this ever increasing demand, fossil fuels such as coal, oil and natural gas have been overexploited in an unsustainable manner. The overexploitations of fossil fuels have been posing serious environmental problems such as global warming and climate change. While we have shortage of energy and more dependent on imports in case of petroleum, we are fortunate enough to be blessed with plenty of natural sources of energy such as solar, wind, biomass and hydro. These sources are environmentally benign and non-depleting in nature as well as are available in most parts of the country throughout the year.

Among the natural sources, biomass resources such as cattle dung, agriculture wastes and other organic wastes have been one of the main energy sources for the mankind since the dawn of civilization. The organic carbon based material of plant and animals is called biomass and Biogas production is a clean low carbon technology for efficient management. Biogas is a versatile renewable energy source, which can be used for replacement of fossil fuels in power and heat production, and it can be used as gaseous vehicle fuel. Methane rich biogas can also replace natural gas as a feedstock for producing chemicals and materials (Weiland et al,. 2009). Many innovative ideas and growing technologies have proved that waste can be used as an alternative energy source. So, in order to compete with the increasing energy demand and simultaneously minimize the entry of waste into the environment, the mankind generated biomass waste (Nallathambi et al., 1997) and treatment plant sludge (Malik et al,. 2009) can be used for methane enrichment.

The process that is involved in converting biomass into biogas is the anaerobic digestion. Traditionally, anaerobic digestion was a single substrate, single purpose treatment. Recently, it has been realized that AD as such became more stable when the variety of substrates applied at the same time is increased. Hence, a great option for improving yields of anaerobic digestion of solid wastes is the co-digestion of multiple substrates. Co-digestion is the simultaneous digestion of a homogenous mixture of two or more substrates. Numerous studies demonstrate that using co-substrates in anaerobic digestion system improves the biogas yields due to positives synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates. Before subjecting a material to anaerobic digestion, its ability to produce biogas can be assessed by Biochemical Methane Potential assay (Owen et al., 1978). The BMP assay has been widely used to determine the methane yield of organic substrates in specific conditions and to evaluate the potential biogas production efficiency of the anaerobic process on a given material. The duration of the test varies depending on the biodegradability of organic substrate under study. The BMP assay is done for different ratios of sample, co-digestate and seed sludge to obtain microbe/ g of substrate for complete conversion into biogas. The production of volatile Fatty Acids will be maximum at optimum carbon to nitrogen ratio and hence the methane production. The information provided by BMP is valuable when evaluating potential anaerobic substrates and for optimizing the design and operation of an anaerobic digester.

2. MATERIALS AND METHODS
2.1 Sample collection:
Waste was collected from CEG canteen of Anna University which contained peels of various fruits and vegetables. This raw mixture of wastes was homogenized using mincer. This process of size reduction provided good contact area to the microbial population.

The co-substrate sludge was obtained from sewage treatment plant in CEG, Anna University. After collection, the sludge is concentrated by dewatering.

2.2 Seed sludge preparation:

Seed sludge refers to a mass of sludge that contains population of microorganism for methane production. For its preparation, the biological sludge from CETP, Pallavaram was collected and before use it was activated by adding the nutrients and the pH was maintained at 6.5.

2.3 Reactor setup

A Serum bottle of 0.5 L capacity was used for batch evaluation of the co – digestion of agricultural waste with secondary sewage treatment plant sludge. The effective volume of the reactor was maintained at 0.4 L, rest of the space was left free as gas collection space. Various compositions of inoculum and substrate were filled in the effective reactor volume. The reactors were purged with oxygen and nitrogen to maintain anaerobic condition. The reactors were stirred by daily shaking and swirling. The reactors were operated with a retention time of 40 days.

Five reactors (C, 1, 2, 3 & 4) were used for this study using C as control for Seed. Different proportions of substrate and inoculum were used in reactors 1, 2, 3 & 4. The samples were taken out for analysis, not daily but once in ten days to maintain anaerobic condition inside the reactor.

Table 1: Bottling composition

Ratio	Labeling	Feed Composition (ml)		
		Seed Sludge	**Waste**	**STP Sludge**
1:0:0 (Control)	C	400	-	-
1:2:1	1	100	200	100
2:1:1	2	100	100	200
3:1:1	3	80	80	240
1:3:1	4	80	240	80

3. RESULTS

The parameters such as Alkalinity, Chemical Oxygen Demand (COD), Ammonia and Volatile Fatty Acids (VFA) were calculated once in ten days to monitor the process inside the batch reactors. All the testing procedures were based on APHA.

3.1 Alkalinity:

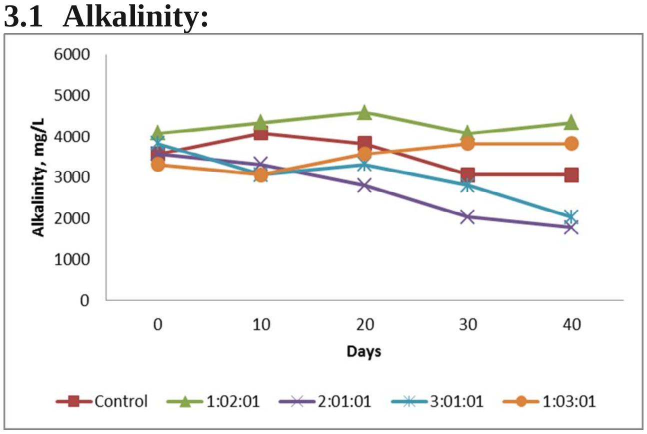

Figure 1: Alkalinity

Alkalinity is the buffering capacity of substrate and mostly present in the form of bicarbonate in liquid phase. Carbon dioxide and ammonia are produced during the consumption of proteins and amino acids in the substrate. Being soluble in water, the release of ammonia leads to the formation of ammonium and provides a major source of hydroxide ions. These hydroxide ions interact with carbon dioxide to form bicarbonates which buffers the substrate at low pH. The above graph shows the prevalence of total alkalinity during the digestion process. It can be seen that no value of alkalinity exceeds 6000 mg/L above which the reactor would become unstable. The ratios 2:1:1 and 3:1:1 had decreasing trend during the digestion period and was accumulated with VFA and hence showed poor gas production. While the ratios 1:2:1 and 1:3:1 had increasing trend and buffered the substrate well against VFA. The alkalinity addition reduced the waste quantity, the organic content of the solid waste and the biodegradation time.

3.2 Volatile Fatty Acids (VFA)

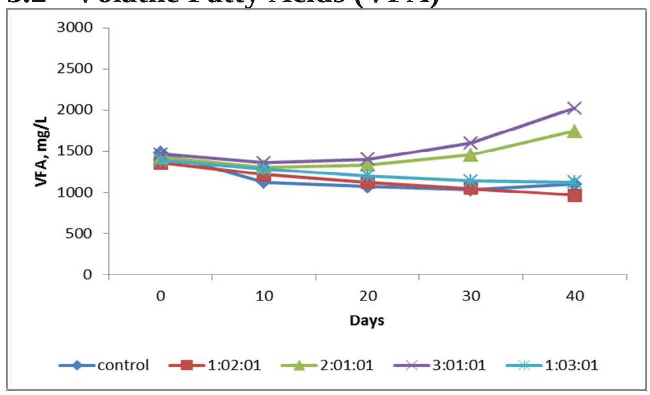

Figure 2: Volatile Fatty Acids (VFA)

The figure displays the VFA concentration in each bottle. VFA is an important intermediate for the production of methane. The methanogens should consume these VFAs as soon as they are produced so that the pH remains in tolerable range. If not so, VFA may happen to accumulate in the reactor. Since the methanogens are very sensitive to pH fluctuations, accumulation of VFA beyond buffering capacity of the substrate will be lethal to methanogens (Ahring et al., 1995) and hence, poor gas production. In this study, the ratios 1:2:1 and 1:3:1 had shown an optimum concentration of VFA which in turn had a proper gas production. But the ratios 2:1:1 and 3:1:1 had accumulation of VFA and hence showed poor gas production.

3.3 Chemical Oxygen Demand (COD)

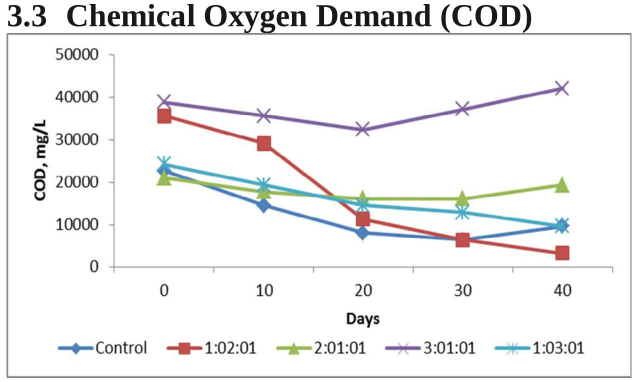

Figure 3: Chemical Oxygen Demand (COD)

The above graph shows the trend of COD during the BMP test period. As the bacteria feed on the organics present in the substrate, the COD should fall during digestion and at the end, as there will be no more organics, COD may rise due to the accumulation of dead bacterial population with corresponding fall in gas production. The ratios 1:2:1 and 1:3:1 had decreasing trend throughout the process while the ratios 2:1:1 and 3:1:1 had a sudden rise in COD with corresponding slip in the gas production from the 30th and 20th day of bottling respectively.

3.4 Ammonia

The following graph depicts the concentration of ammonia in each bottle during the period of BMP test. Since the nitrogen is essential for the proliferation of biomass, the consumption of nitro compounds will ultimately lead to the production of ammonia and ammonium compounds. The accumulation of ammonia until a certain limit will not bother the methanogens but beyond that, poses a serious threat to methenogens. It was already reported that inoculum acclimatized to free ammonia concentrations could be able to tolerate elevated free ammonia concentrations upto 800 mg/L. In this study, all the ratios had tolerable concentration range and hence it can be concluded that failure was not due to ammonia accumulation in the reactors 2 and 3.

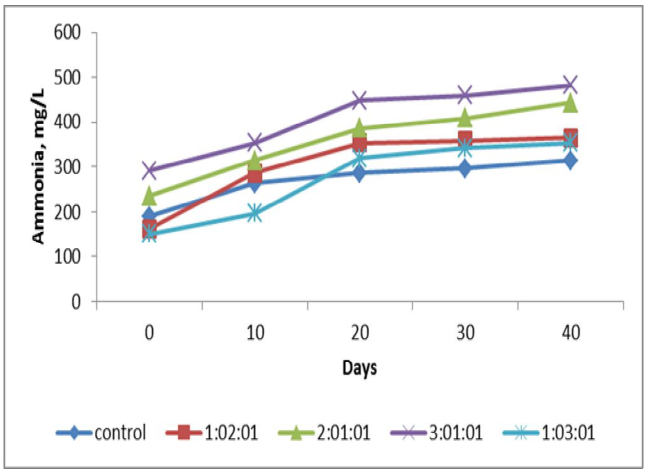

Figure 4: Ammonia

3.5 Cumulative gas production

Gas produced in each bottle was measured everyday by water displacement method using aspiration bottle. The aspiration bottle was filled with 5% sodium hydroxide and few drops of phenolphthalein indicator were added which would help to know the condition of saturation. This solution was the used to scrub carbon dioxide and approximated methane volume alone was measured. From the graph, it can be seen that the ratio 1:2:1 had the maximum gas production of 4.632L during the entire test period with highest production of 489 mL/day at the 22nd day of bottling. The ratio 1:3:1 had a total gas production of 2.119 L but this seems to be very less when compared with the ratio 1:2:1. While the other two ratios (2:1:1 and 3:1:1) had poor gas production and the reason may be poor buffering and VFA accumulation.

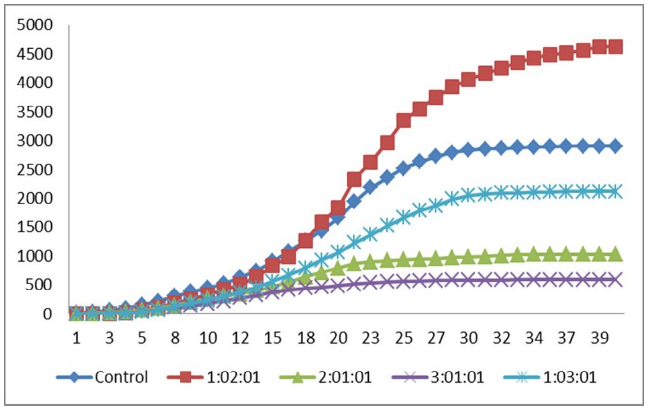

Figure 5: Cumulative gas production

4. CONCLUSION

The BMP test and analysis were done successfully. It can be inferred from the results that the ratio would be one part of agricultural waste and two parts of sewage sludge along with one part of seed sludge is the optimum proportion as this generated a constant and steady biogas production throughout the batch period.

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