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RESEARCH ARTICLE

STUDY ON THE INFLUENCE OF THE CHARACTERISTICS OF SUBSTRATES IN BIOGAS PRODUCTION

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ABSTRACT

The objective of the study is to determine the characteristics of three different substrates-sewage sludge from waste water treatment plants, waste grown algae and the waste paper from the waste bins - and the influence of these characteristics on biogas production when they are added in a batch reactor under the anaerobic digestion. Integration of sewage sludge with waste paper and algae in anaerobic co-digestion has a great advantage on the treatment of sludge from Municipal Wastewater Treatment plants (WWTP). The study assess the bio methane potential and kinetics of biodegradability of the substrates before they are added for a co digestion. The bio-methane potential study shows that the three substrates are biodegradable and can complement each other if used in co-digestion. From the degradation study it is found that degradation kinetics of the sludge is almost 50% faster than the waste paper and 33% faster than the algae.

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INTRODUCTION

According to the report of UNFA 2007, the speed and scale of urbanization and the population today are far greater than in the past and it reflects severe effect on the environmental economic and social balance of the nature. This scenario led to the unprecedented increase in the atmospheric concentrations of carbon dioxide, methane and nitrous oxide ever before and the magnitude of increase in temperature in the atmosphere. Concentration of these greenhouse gases (GHG) in the atmosphere escalates the global warming. In view of the GHG emissions and trimming down the fossil fuel reserves, it is enforced to find an alternative low carbon energy sources. In this context, biogas from wastes, residues, and energy crops will play a vital role in future. Large amount of sludge is daily produced at waste water treatment plants (WWTP). Waste grown microalgae are also a promising biomass for the biofuel production. The organic fraction of Municipal Sludge creates a nuisance to the landfills and continue to cause environmental problems. Algae is a photosynthetic organism that utilises sunlight and freely available raw materials such as nutrients from wastewater and CO_2 from the atmosphere to synthesize and accumulate large quantities of neutral lipids and carbohydrates. To a certain extent algae can reduce the environmental impact and waste disposal problems. Also, it can play a major role in the treatment/utilization of waste water. The production of biogas through anaerobic digestion offers significant advantages over the other forms of bioenergy production. It has been appraised as one of the most energy-efficient and environmentally beneficial technology for bioenergy production. These technologies can maximise recycling and recovery of waste components to a value added product. Sewage sludge is regarded as the residue produced by the wastewater treatment process, during which liquids and solids are being separated. It is the nutrient-rich organic materials resulting from the treatment of domestic/industrial sewage in a wastewater treatment facility. Feedstock is defined to include any substrate that can be converted to methane by anaerobic bacteria. The main components of organic waste are Carbon, oxygen, nitrogen, hydrogen and phosphorus).And, the microbial cell material in the feed stock consists about approximately 50, 20, 12, 8 and 2 % of those elements, respectively. The carbonaceous organic matter in wastewater is referred to as the substrate which is converted during biological treatment. The anaerobic digestion is strongly depends on the type, availability and complexity of the substrate. Algae are simple microorganisms which are either aquatic or microscopic. It may be autotrophic, heterotrophic or by mixotrophy. They are consuming Carbon dioxide from the

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atmosphere or environment, and using the sunlight produce either carbohydrates or fat or oil and proteins. Through any of the three processes, algae can produce carbohydrates, lipids and proteins over a short period of time, which can then be processed to generate biofuels. The biomass of algae are composed of three essential components namely carbohydrates, proteins and natural oils. Pulp and paper industries are the most polluted in the world. Also, it consumes more energy and water. The major raw material for pulp and paper production is trees which contains cellulose fibers, other carbohydrates and lignin. These waste are the fraction of a municipal solid waste and are not always source-sorted, but can be directly added for anaerobic treatment. . Main characteristic of the cellulosic wastes is the very 'high 'C/N ratio' in the range of '173 – 1000'. The 'C/N ratio' suggested for the optimum production of biogas for anaerobic digestion process is 20–30. The organic waste degraded in the absence of oxygen by a groups of microorganisms is termed as anaerobic biodegradation. During the stages of anaerobic digestion, the degradation steps are carried out by different consortia of microorganisms. Angelidak (1992) and Wieland (2007) suggested that hydrolysing and fermenting microorganisms are responsible for the initial attack on polymers and monomers and produce mainly acetate and hydrogen and varying amounts of volatile fatty acids such as propionate and butyrate. The measurement of the methane yield and the kinetics of degradation of the organic matter of particulate substrates in batch reactors presents several advantages compared to the traditional BMP measurement method: (i) The measurement made with acclimatized biomass as the experimental protocol in batch reactor is required in successive batches until the biogas profiles of one batch is similar to the other. Indeed, experiments carried out in batch reactors have shown that the kinetics of the first batch is very often quite different from that of the other batches. So it is very important to take this into account for the measurement of the kinetics of degradation. The volume of biogas produced over time during the batches can be monitored online making it possible to measure accurately the kinetics of biogas production for each batch. This study was undertaken to provide the bio methane potential of the substrates algae, paper and sludge and also to find the biodegradation and degradation kinetics of these substrates. Also, the study will lead to find the possibility of the co digestion of these substrate.

MATERIALS AND METHODS

Substrates

This paper focuses on characterization of municipal sludge, waste paper and algae as substrates to be used in co-digestion. The sludge samples were collected from primary tank of an activated sludge treatment plant handling municipal wastewater. Sewage sludge collected from the primary settling tank of WWTP was mixed homogeneously and allowed to settle. The settled sludge was then concentrated to 4g/l. Scendesmus obliquus is a freshwater micro algae that can grow in industrial wastewaters of different origins showing good adaptation ability. And, it is a very versatile microalgae as raw material for biofuels production (Miranda *et al*., 2012). In the present study the microalgae cultivated in municipal wastewater in 1.5x0.7x0.7m glass tank with a provision of supplying carbon dioxide and oxygen. Algae cultured at the lab was collected and passed through a micro-sieve to remove the other impurities. The laser print waste paper collected from the waste bin of computer centre was shredded into pieces of size 0.5x0.5 cm.

Reactors

The experiments were carried out in a reactors of 6-L effective volume with double wall shown in Figure 1. The temperature has been maintained in mesosphelic range (35±2 °C) by a regulated water bath. A system of magnetic stirring was used for the continuous mixing inside the reactor. The biogas production was measured on-line by Millie gas counter MGC-1 flow meters (Ritter gas meters) fitted with a 4-20 mA output. The software supplied by the manufacturer was used to count the gas output.

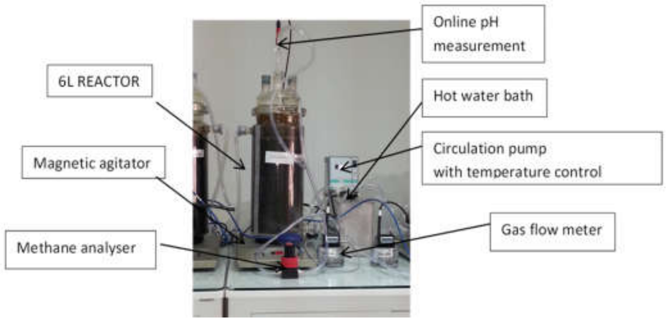

Figure 1. Experimental Set-up

Inoculum

The reactors were seeded at a volatile suspended solids concentration (VSS) of around 24 g VS/l with horse dung. After seeding and before starting the addition of the waste, the reactors were fed 2ml and 5 mL of ethanol as sole source of carbon and energy to confirm the activity of the sludge. Sampling and analysis: The pH inside the reactor was continuously monitored online and maintained at 7.5±0.5, using Metler Toledo pH probe Inpro 4260i. Biogas volume and biodegradation of substrate was calculated as a function of time. The samples from the reactor was collected before the feed of each of the batch and analysed for Thermal conductivity (TC), Total solids (TS), Suspended solids (SS), volatile suspended solids (VSS) and chemical oxygen demand (COD). The biogas volume and flow rate was recorded online through data acquisition software supplied by Ritter milli counter gas flow metre. The COD soluble was determined using HACH digestion method. The characteristics of the substrates is shown in Table 1.

Table 1. Characteristics of Substrates

Substrate	%TSS	%VS	TC gm/Kg VS	TKN gm/Kg VS	C/N
Sewage Sludge	10.66	71.89	85	13	13
Waste Paper	4.58	55.69	475	3.5	135
Algae	10.34	74.6	105	20	5.03

RESULTS AND DISCUSSION

Reactor was operated for 55 days initially to study the digestion performance of the substrates separately. The observation of the parameters and the analysis is shown below in Figure 2,3, 4and 5.

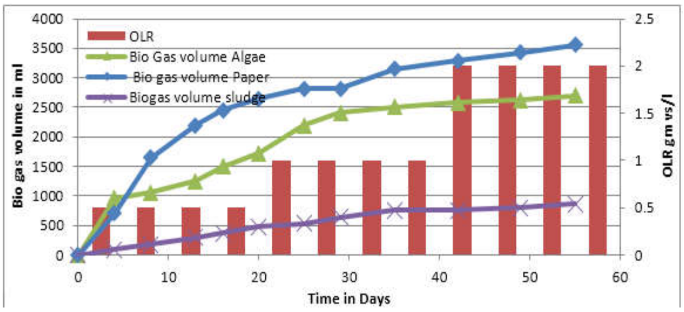

Figure 2. Biogas Volume of the Substrates

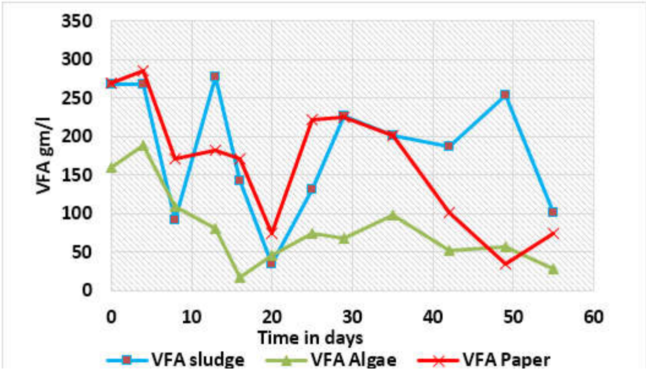

Figure 3. Volatile Fatty Acid Concentration vs. Time in mono substrate digestion

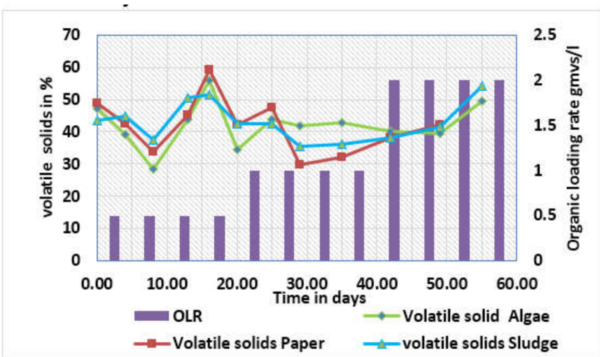

Figure 4. Volatile solid Concentration vs. Time in mono substrate digestion

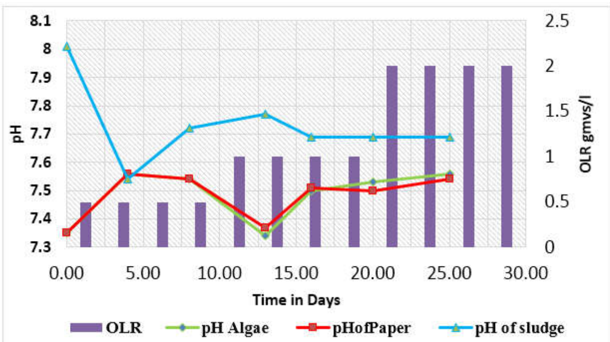

Figure 5. Variation in pH vs. Time in mono substrate digestion

From the observations of the digestions of the substrates it was observed that biogas volume produced by the sewage sludge is less compared to the algae and wastepaper. Also for the substrates algae and waste paper, COD reduction is about 60-80% compared to the sewage sludge. The reduction in COD and VSS is significant in the digestion performance in the case of algae and waste paper. It was observed that a decrease in pH and an increase in VFA concentration in the reactor fed with algae. Accumulation of the VFA concentration affects the pH and subsequently biogas volume was reduced. If the loading rate is kept increasing, the VFA concentration will exceed the limit and the reactor becomes unstable due to the acidification. Considering the start up time for the biogas production it was observed that sewage sludge started the reaction/production of the biogas early about 4-5 hours and for paper start up time was observed between 20-24 hours and for the algae between 15-20 hours. Higher cellulose content in the paper and thickened cell walls of the algae be the reason for this delay in the reaction.

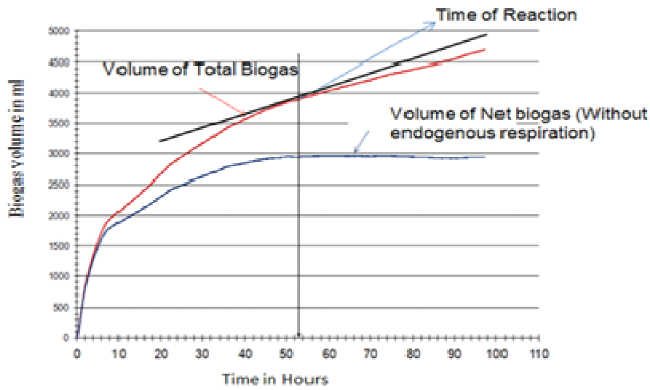

Fig. 6. Typical curve showing total biogas and derivative of net biogas VS time: Reproduced from

Bio Degradation study of the substrates

It is common in anaerobic reaction that biogas is continued to produce and it was difficult to identify and understand the end of the reaction. When the biogas volume produced was very low or the flow rate is reduced, then it was considered as the end of the reaction. Calculation of the biogas produced during the endogenous phase is illustrated in Fig.6. Segregation of these two phases is very difficult. When the reaction was over and the organic matter added was eliminated at the end of the batches, the biogas production rate became very low. The time when the sludge was back to its endogenous activity could be assumed as per Figure 6. The net biogas production is calculated by subtracting the endogenous respiration from the total volume of biogas produced. The average specific kinetic of degradation was calculated by dividing the quantity of substrate added (in VSS) by the duration of the batch and by the volatile suspended solids (VSS) concentration in the reactor. The figure 6 shows the typical plot total and net biogas with time.

$$\text{Biomethane Potential (BMP)} = \frac{\text{Biogas Volume} \times \%\text{ of methane}}{\text{Organic Loading rate (OLR)} \times \text{Effective volume of reactor}} \quad \text{--- (1)}$$

$$\text{Degradation kinetics} = \frac{\text{Amount of Volatile suspended solids added} \times 24}{\text{Time} \times \text{Volatile suspended solids inside the reactor}} \quad \text{----- (2)}$$

The average specific kinetic of degradation was calculated by dividing the quantity of substrate added (in VS) by the duration of the batch and by the volatile suspended solids (VS) concentration in the reactor. This parameter was also measured when 80% of the total volume of biogas was produced. In this study, the organic matter of the substrates were divided into compartments according to the degradation kinetics of the substrates. (e.g. rapidly or slowly biodegradable). From Fig.7

the net biogas yield for sludge was found to be 100 ml/h, and for paper and algae, between 175 – 325 ml/h. The specific degradation kinetics values were different for all the three substrates. Paper had low degradation kinetics when compared to Sludge and algae. The methane yield of algae and paper was more when compared to sludge in Fig.8. The increase in cellulose activity resulting from paper was another possibility for increase in methane yield (Ammonia inhibition and 'recalcitrant cell walls' are commonly cited causes of the lower yields from AD (Anaerobic Digestion of algae). For algae the ammonia accumulation is caused by the high Nitrogen content causing low C/N ratio and high carbon materials like sludge and waste paper has been suggested as suitable co-digestion substrate. The degradability of the microalgae seemed to be limited possibly due to the resistance of the micro algal cell wall.

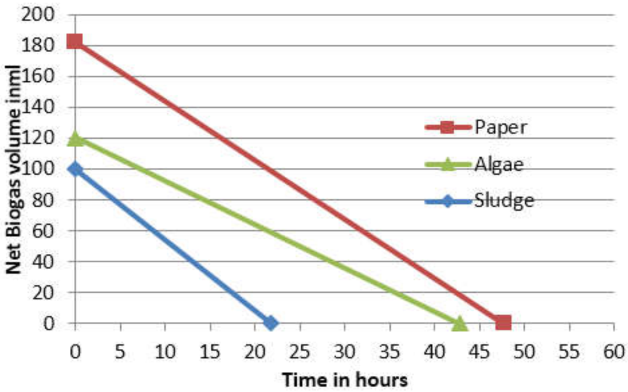

Figure 7. Net biogas vs. time for Sludge, Paper and Algae

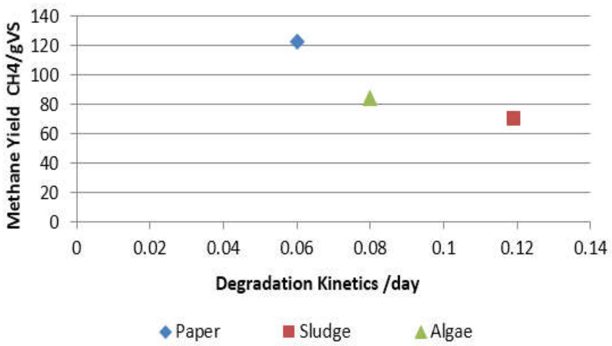

Figure 8. Methane yield and degradation kinetics for Sludge, Paper and Algae

Conclusion

Characteristic study of the substrates showed that all the substrates were produced biogas. Under anaerobic conditions all the three substrates were well digested by itself. Increase in organic loading rate generates VFA accumulation in the reactor which affected the pH and biogas production inversely. The bio-methane potential study shows that the three substrates are biodegradable and can complement each other if used in co-digestion. The waste paper and algae can balance C/N ratio and can increase the cellulose activity. From the degradation study it is found that degradation kinetics of the sludge is almost 50% faster than the waste paper and 33% faster than the algae. It can be concluded that a synergetic effect at mesophilic conditions will be formed in the reactor at the time of co digestion of these substrates and it will enhance the biogas production by balancing the nutrient composition in the reactor. The degradation kinetic study helps to compartmentalise the substrates to slow, medium and fast degrading. This might help to assess initially, the proportion of each of the substrates when put into the reactor in co-digestion, which would finally improve the methane potential.

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