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Effect of Different Inoculum/Substrate Ratios on Anaerobic Digestion of Pulp and Paper Mill Sludge

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Abstract: ***Pulp and paper industry is considered as one of the most polluted industry in the world and also energy and water intensive. Paper industry produce huge amount of wastewater, hence sludge production is a major issue. Conventional sludge management methods such as landfilling produce leachate and incineration emits greenhouse gases, therefore public opposition and strict regulatory pressure have been perceived in many countries. Anaerobic digestion a versatile technology for alternative disposal options. The aim of this study was to evaluate the effect of different inoculum/substrate (I/S) ratio on the anaerobic digestion of pulp and paper mill sludge (PPMS). A laboratory scale reactor was used to analyses the four different I/S ratio varies from 1.0 to 2.5 plus control on VS basis were used for this study. The different parameter i.e. pH, volatile solid, volatile fatty acid and cumulative methane production from different I/S mixture was measured and it was observed that the maximum methane production of 3329 mL was achieved in I/S ratio 2.0. Hence the study concluded that I/S ratio of 2.0 was good for better methane production.***

Keyword: pulp and paper mill sludge, anaerobic digestion, inoculum/substrate ratio, methane.

1. Introduction

Pulp and paper industry is considered as one of the most polluted industry in the world [1]. These processes generate wastewaters which are then treated by the physical, chemical as well as biological treatment. Wastewater treatment plants eventually produces pulp and paper mill sludge (PPMS) from chemical and biological treatment in large quantities, ranging from 0.3 to 1 m^3 of PS/ton paper produced. In India, there are about 759 pulp and paper industry is available. They generate 1.51 million tonnes of sludge per year [2]. Of this 45-50% is made up of organic fraction and contains many kinds nutrient component [3]. The traditional management methods such as landfilling producing leachate and incineration which emits greenhouse gases have come under strong public opposition and strict regulatory pressure in many countries. This has forced the industry to seek alternative disposal options. Growing worldwide energy demand and increasing concerns of Energy security and climate change have led to the development of alternative energy source like anaerobic digestion (AD), which is well renowned technology for renewable energy generation through non-oxidative metabolism. This renewable source has to augment and replace fossil fuel transportation. AD is a microbial- mediated process in which trillions of naturally occurring bacteria and archaea to do the biodegradation for producing renewable energy from discarded organic materials. In this organic matter is metabolized to methane (CH_4) and carbon dioxide in the absence of atmospheric oxygen. The energy recovered from AD of pulp and paper mill derived sludge is renewable and the effluent can be returned to the agricultural land, recovering the remaining organic matter and nutrients. AD has unique and integrative potential, simultaneously acting as waste treatment and resource management. AD has been successfully used for sludge treatments of various kinds for example sewage sludge [4], waste activated sludge [5] and cow manure [6]. However, very few studies have applied AD for PPMS treatment. Lin et al [7] demonstrated that PPMS combined with monosodium glutamate waste liquor can produce up to 200 ml methane/g volatile solid (VS)added, with methane reaching up to 80% of the total biogas composition. However this study was conducted at controlled temperature of 37^o C, that why it's not favorable for medium scale industries. Soetopo et al., [8] showed that the highest biogas methane content from AD of PPMS is 51.5% at the rate of 140 ml/g VS in 28 days. Nonetheless, this study was accompanied using only sludge from secondary biological wastewater treatment. This is also less applicable for most industries; PS originating from primary physical-chemical wastewater treatment can make up to 98% of sludge produced. Thus, this study aims to investigate the rate and extent of the anaerobic digestion of different I/S ratio derived from primary sludge of pulp and paper wastewater treatment under uncontrolled temperature.

2. Material and Method

2.1. Substrate and Inoculum

The sludge originated from a pulp and paper industry in Nagaon paper mill situated at Jagiroad, Assam, India. Sludge used in this study was collected from the sludge holding tank from primary clarifier that is composed of primary sludge. Samples were collected and conserved at 4^{o}C before feeding to the reactors. Seed sludge (Cow dung) was obtained from a nearby farm in Amingaon, IIT Guwahati, India and used as inoculum for the BMP assay.

2.2. Experimental Devices

The anaerobic reactor was prepared using 1 L reagent glass bottles with rubber corks for closing the bottles. For different I/S ratio, 15 batch reactors were used, 12 reactors were fed with different amount of PPMS with essential macro and micro nutrients in addition of 100 g of inoculum. Rest of the 3 reactor was used as a control with only 100 g of inoculum, macro and micro nutrients. Finally all the 15 reactors were made up to 500 mL using distilled water. To maintain anaerobic condition nitrogen gas was purged inside all the 15 reactors. After that, all the reactors were connected to aspirator bottles having 1.5 N NaOH and the methane produced was measured. The reactors were maintained at room temperature approximately 30^{o}C. The experiment was conducted for 42 days with triplicate.

2.3. Sampling

Sludge of about 40 mL was collected as a sample from each reactor once in a week to measure for volatile solids (VS) and volatile fatty acids (VFA). VS was analyzed for the PPMS using standard protocols according to APHA [9]. VFA was measured using DiLalo and Albertson [10] pH titration method. Biogas production was measured daily by Water

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displacement method. The reactors were connected to aspirator bottles filled with 6% NaOH to quantify the amount of gas produced and measure the amount of NaOH replacement due to accumulation of biogas in gas collection system.

3. Results and Discussion

Even though temperature was uncontrolled, during the course of time steady temperature ranging from 29-33^{o}C was maintained which indicating mesophilic range. From this study it was observed pH values varied in the range 4.8–7.5 during AD. In order to investigate the role of substrate nature different I/S ratio were performed using smaller amount of seed culture. In this case, only VS-degradation was monitored. A small drop in pH value was observed in all experiments during the course of the reaction. However, in all cases, the final pH values remain above 6, suggesting low acidogenic activity, most likely limited by the rate of hydrolysis. The rate of VS-degradation is lower in I/S ratio lower than 1.5 as compared to the VS-degradation of I/S ratio 2.0, which was the batch test with an appropriate proportion of anaerobic seed culture and buffer. This difference might be a consequence of lack of nutrition, lower pH and long lag phase due to microorganism culture growth. It could be argued that the appropriate AD organisms may have been showed I/S ratio 2.0 has higher methane production when compared to other I/S ratio lower than 1.5 and greater than 2.5. The VS reduction during the period of anaerobic digestion with different I/S ratio was represented in Fig.1.

Batch wise anaerobic digestion was chosen as the main approach for methane production to facilitate the study of many variations. The variable of primary interest is the amount of methane produced during the course of a batch run. In order to analyze this, the volume of biogas was measured. Methane production was a visual index to evaluate the performance of anaerobic digestion. As shown in Figure 2, the methane yield of each I/S ratio were ranked in the order 2.0>1.5>2.5>1.0 during the period of anaerobic digestion, with the duration of 42 days.

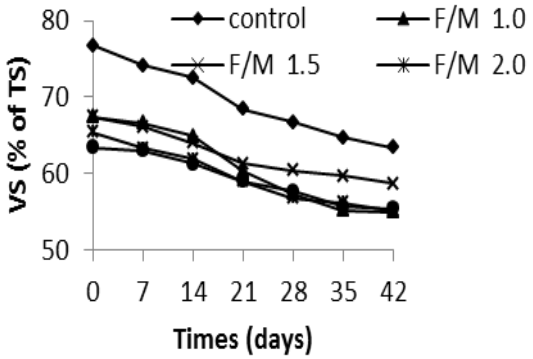

Fig. 1 The VS reduction during the period of anaerobic digestion with different I/S ratio

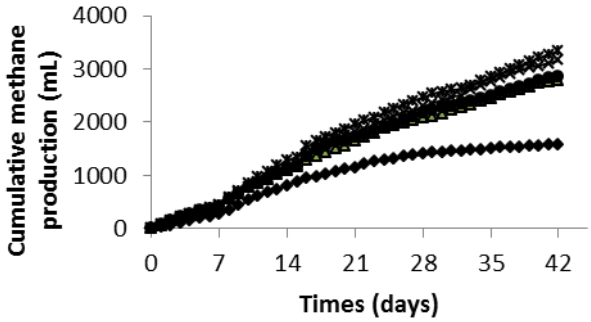

Fig 2. The methane yield in the anaerobic digestion different I/S ratios

Generally, the VFA concentrations during anaerobic digestion increased to a peak value due to the degradation of organics by acidogenic bacteria and then decreased to a minimum due to the methane production by methanogenic bacteria. In this test, the VFA concentrations in each I/S ratio were ranked in the order 2.5>2.0>1.5. For varied I/S ratio, the VFA concentration was much higher than that in I/S ratio 2.5, but the methane yield in I/S ratio2.0 was larger than that in ratio. Considering VS, VFA and methane production, each I/S ratio seemed to go through different pathways for methane production. This suggested that methane production in I/S ratio 2.0 went from hydrolysis directly to methanogenesis. Afterwards, methane was produced through the acetogenesis process, explained by the decrease of VFA in I/S ratio 2.0 and an increase in methane. The slow production of methane for I/S ratio 2.0 as well as the VFA suggested that I/S ratio 2.0 followed the typical AD pathway of hydrolisis, acidogenesis, acetogenesis and finally ending with methanogenesis.

4. Conclusion

Sludge generated from pulp and paper industry also contributed a high potential for energy recovery. It was observed that the maximum methane production of 3329 mL was achieved in I/S ratio 2.0. Hence the study concluded that I/S ratio of 2.0 was good for better methane production. Uncontrolled temperature also an additional advantage for this process which makes it more applicable to medium scale industries.

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