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RESEARCH ARTICLE

ASSESSMENT OF WASTE TREATMENT AND ENERGY RECOVERY FROM DAIRY INDUSTRIAL WASTE BY ANAEROBIC DIGESTION

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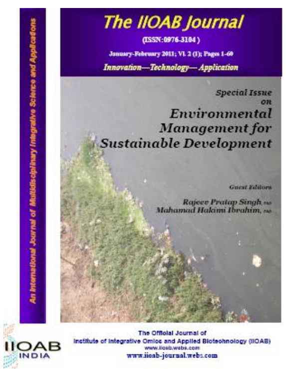
ABSTRACT



Waste treatment with simultaneous energy generation was studied in anaerobic digester using dairy industry waste (sludge, influent) as substrate. No pretreatment or solid liquid separation was applied. Batch fermentation experiments were performed with three different substrates at organic pollution load (OPL) under mesophilic range of temperature (30±2°C). Experimental data evidence the effectiveness of waste on both the removal efficiency in terms of substrate degradation and biogas yield, particularly at higher loading rates. Among the three substrates evaluated, alternative substrates showed comparatively effective performance in comparison to conventional one. However, COD removal efficiency was also found to be effective in operated environment. The described process provides the dual benefit of waste treatment with simultaneous green energy generation in the form of biogas utilizing it as substrate.

Keywords: ***waste treatment; anaerobic digestion; organic pollution load; energy recovery***

[I] INTRODUCTION

The generation and disposal of large quantities of organic waste without adequate treatment results in significant environmental pollution. Some of the waste streams are treated by conventional means like aeration, which is both energy intensive and expensive, and generates a significant quantity of biological sludge, which must then be disposed off. This biological sludge is a big problem at land-filling sites. In this context, anaerobic digestion process is increasingly recognized as economical and important step for biodegradable organic matter removal from wastewater. It is the more stable process for medium and high strength organic effluents. Apart from treating the wastewater, the biogas produce from the anaerobic process can be recovered. The anaerobic process may be perceived as a potential alternative as it not only provides renewable source of energy but also utilizes recycling potential of degradable organic portion of waste generated by a numerous activities in the country.

Anaerobic digestion is a well established process for treating many types of organic wastes, both solid and liquid [1–7, 24]. This alternative allows the recovery of energy and a solid product that can be used as an amendment of soils [8, 9]. This nutrient content of the anaerobic compost is favourable and the content of pollutants is low [10–12]. The conditions which are most important and should be considered while designing an anaerobic digestion system include-pH, temperature, total solid content, retention time, organic loading rate, carbon to nitrogen ratio and mixing.

This waste management technology capable of maintaining both environmental and energy concerns because it has dual benefits i.e. pollution control and energy production with microbiological degradation of organic pollutants, reduction of global warming potential, diminishment of odor and of course the meeting of world energy and economic needs by reducing the reliance on fossil fuels. With increasing use of anaerobic technology for treating various process streams, it is expected that industries would become more economically competitive because of their more judicious use of natural resources. Therefore, anaerobic digestion technology is almost certainly assured of increased usage in the future. Anaerobic treatment converts over half of the effluent COD into biogas [13]. Anaerobic treatment can be successfully operated at high organic loading rates; also, the biogas thus generated can be utilized for steam generation in the boilers thereby meeting the energy demands of the unit [14]. Further, low nutrient requirements and stabilized sludge production are other associated benefits [15].

Now a day water resources are polluted by varied sources, the most critical of which are city sewage and industrial waste discharge. Sewage contributes about 60 % of the total pollution load in terms of biochemical oxygen demand (BOD). In the industrial sector, water pollution is caused by a few industrial sub sectors (food processing industries, paper and pulp industries, textile, agro based industries and chemical industries), which release toxic wastes and organic pollutants [16]. Among all these industrial sub sectors, food-processing industries (dairy, edible oil and confectionary) are the major contributor for wastewater generation. The wastewater from food-processing industries is very rich in organic contents and may be a potential source for production of methane gas. There are over 18,550 food processing industries in India, emanating large quantities of wastes [17]. These wastes are either uneconomically utilized or disposed off without treatment, thereby causing serious pollution problems. With the 50% of moisture content or above, it is found that bio-conversion processes are more suitable than thermo-conversion process [18]. Wastewater from a dairy operation consists of water that has been used for plant washing, processing and cooling purposes [19]. Water management in the dairy industry is well documented [20], but effluent production and disposal remain a problematic issue for the dairy industry. To enable the dairy industry to contribute to water conservation, an efficient and cost-effective effluent treatment technology has to be developed. To this effect, anaerobic digestion offers a unique treatment option to the dairy industry. Not only does anaerobic digestion reduce the COD of an effluent, but little microbial biomass is produced. The biggest advantage is energy recovery in the form of methane and up to 95% of the organic matter in a waste stream can be converted into biogas [21].

Therefore, the objective of this work was to assess anaerobic digestion of dairy industrial waste (sludge and influent). To these purpose seven anaerobic digesters with and without cattle dung were operated in two phases. All digesters were fed with various mixing concentrations to determine the removal of organic load and energy generation from the system.

[II] MATERIALS AND METHODS

2.1. Waste collection and storage

The wastewater (influent) and sludge were collected from Dairy Industry Pvt. Ltd. Lucknow, whereas cattle dung was collected from the nearby area of the university campus of BBAUniversity, Lucknow (India). Collected sample were stored in plastic container at 4°C prior to use.

2.2. Experimental set-up

Total experimental study was divided into two phases. In Phase-I set-up all the three digesters contain pure feedstock materials (P1, P2 & P3) whereas Phase-II has mix compositions of pure feedstock materials (M1, M2, M3 & M4) with inoculum, are in the anaerobic condition with suitable temperature, required for anaerobic process depicted in [Table–1].

Table: 1. Composition of waste slurry digesters and control digesters

Serial No.	Raw Material	Composition
	Phase-I	
P1	Sludge +Distilled water	1:1 = 2.5 liter
P2	Influent (pure)	1:1 = 2.5 liter
P3	Cattle dung+Distilled water	1:1 = 2.5 liter
	Phase-II	
M1	Sludge+cattle dung	1:1 = 2.5 liter
M2	Sludge +Influent	1:1 = 2.5 liter
M3	Sludge +Influent+Cattle dung	1:1:0.5 = 2.5 liter
M4	Influent (pure) +Cattle dung	1:1:0.5 = 2.5 liter

Batch experiments were carried out in two phases with identical digesters of 5 L capacity each with liquid displacement system for biogas collection. The containers were made air tight with a rubber stopper through which a gas collection tube passed. The other end of the tube was connected to a bottle, which was filled with alkali solution (2N KOH) to dissolve the amounts of CO_2 and H_2S gases.

The digester containers were maintained at mesophilic temperature 30±2°C with temperature controlled water baths. The stirring of water in the tank to obtain a uniform temperature throughout, was done by circulating water with the help of motor pump. The digesters were fabricated using leak proof sealing along with proper inlet and outlet arrangements.

Digester feed was prepared using without and with inoculum mixing it with dairy industry waste samples for both phases. In the phase-II study, use of cattle dung as inoculum is the main feature with sludge and wastewater at various concentrations. Inoculum is one of the factor which have a wider role in energy (biogas) production. The feed was homogenized in mixing tank with the help of manual mixing mechanism. The required volume of homogenized slurry was then fed into the experimental digester. Feeding was done once in all the digesters.

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Total experiment was carried out for 50 days. The content, of the digesters were mixed thrice a day by stirring manually upto 10 minutes to maintain intimate contact between the micro-organism and substrate. Details of reactor operation are given in **Table– 2**.

Table: 2. Details of digester operation

Mode of digester operation	Periodic conditions
Digester microenvironment	Anaerobic
HRT	50 days
Operating Temperature	30±2°C
Feed Volume	2.5 liter
Digester Volume	5.0 liter

2.3. Analytical methods

Chemical Oxygen Demand (COD), Bio-chemical Oxygen Demand (BOD), Total Solid (TS), Total Organic Carbon (TOC) and pH analysis were performed at the Environmental Quality Lab as described in Standard Methods of APHA, 1995 at pre and post digestion period for both phases. Carbon, measured as TOC (total organic carbon), is a main factor for the energy content of organic compounds. Therefore the carbon balance very much represents the energy balance in sewage/sludge treatment processes. Gas production was monitored every fifth day by a water displacement device attached to each digester.

[III] RESULTS AND DISCUSSION

Analysis of pre & post digestion period i.e. on Day 1 and after 50 Days HRT for initial and final slurries from all the digesters is presented in Table 3. Percentage removal of organic loading in context of TS, BOD and COD for waste treatment is also given in **Table–3**.

3.1. Phase-I

Two replicate digesters of pure feedstock's containing the same amount of anaerobic feed material were run to determine the reduction in OPL, TS and pH variation simultaneously for biogas generation.

3.1.1. Organic pollution load removal (COD, BOD & TOC) with TS and pH variation

When the pH values of the final slurries from first phase digesters are considered **[Table–3]**, it was observed that slightly increase in the range of digesters i.e. 8.7 (P1), 6.2 (P2), & 8.0 (P3). During anaerobic fermentation, micro-organisms require a neutral or mildly alkaline environment for efficient gas production. According to literature [22–24], a pH between 7 and 8.5 is optimum range for increased gas yield. When the corresponding COD and BOD data are considered, it is observed that initial compositions had a very high organic content. Reduction in organic pollution load is measured as total COD and BOD removed from the digesters after 50 days HRT. These values (1040mg/l (P1), 1413mg/l (P2) & 1280 mg/l (P3) for COD and 336 mg/l (P1), 356 mg/l (P2), 682 mg/l (P3) for BOD) were measured on Day 1 when the digesters have been started with pH values 8.3 (P1), 5.5 (P2) and 7.2 (P3). But, when the final slurries were observed for COD and BOD data, remarkable decreases in the values (885 mg/l (P1), 1260 mg/l (P2) & 520 mg/l (P3) for COD and 201 mg/l (P1), 200 mg/l (P2) & 500 mg/l (P3) for BOD) were measured on Day 50. At the same time, the organic input is decreased by about 11-60% (in terms of COD). Highest % reduction (59.3%) in organic load was measured with P3 digester only, which consists of pure cattle dung as slurry **[Figure–1]**. TOC values are also observed, at initial and final day of the experiment, a gradual decrease in values has been measured. These results fully support the experimental data i.e. the lowest conversion of Phase-I study with pure feedstock slurries to biogas was not obtained at P1 & P2 digesters due to very less amount in % removal (9.6 to 32.8 %) in **Figure–2**.

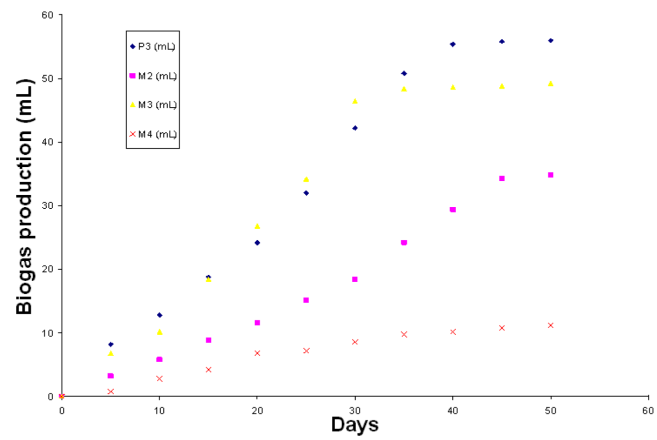

Fig: 1. Cumulated biogas production at 50 days HRT

Generally, the purity of water is determined by the amount of organic matter that it contains in terms of BOD & COD. Similarly, biodegradable potential of the material can be easily accessed by the determination of BOD and its comparison with COD. BOD determines the amount of oxygen required for microbial decomposition in a five days test at 20°C while COD indicates the amount of oxygen necessary for chemical oxidation. According to literature, if BOD/COD ratio is more than 0.6, the organic matter is easily biodegradable if it is between 0.3 to 0.6, then it points to the possibility of biodegradation, and when the ratio is 0.3, then it is not bioamenable [25].

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This statement clearly support the results of experimental Phase-I because minimum biodegradation shown by P2 (0.22) where as maximum rate recorded in digester P3 (0.53).

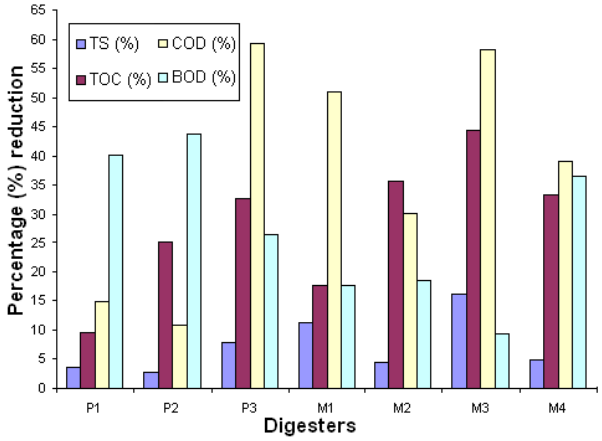

Fig: 2. Percentage (%) reduction in organic pollution load of Phase I & II digesters during study

However, in the present study maximum % reduction was observed for TS with digester P3 (7.8 %) and minimum with digester P2 (2.8 %)

3.1.2. Biogas generation

On an average the biogas production was observed every fifth day interval of total study because no rapid increase was observed for all the digesters for this phase. P1 & P2 follow the same trend i.e. no gas generation till end of the study whereas P3 followed by an increase in biogas generation rate between Days 5-35. Starting with Day 10 biogas production increased gradually up to 55.4 ml/day (Day 40) and then progressively stagnant. A possible explanation is that the soluble and/or easily degradable part of the organics contained in the P3 digester was digested

Table: 3. Pre and post digestion analysis of slurries at 50 days HRT for Phase I & II

Digesters	Parameters													
	pH		TS (mg/l)			TOC (mg/l)			COD (mg/l)			BOD (mg/l)		
	Phase I													
	Initial	Final	Initial	Final	% Removal	Initial	Final	% Removal	Initial	Final	% Removal	Initial	Final	% Removal
P1	8.3	8.7	4100	3950	3.7	1300	1175	9.6	1040	885	14.9	336	201	42.1
P2	5.5	6.2	3500	3400	2.8	700	525	25.0	1413	1260	10.8	356	200	43.8
P3	7.2	8.0	3900	3600	7.8	16000	10750	32.8	1280	520	59.3	682	500	26.6
Phase II														
M1	7.8	8.0	3200	2840	11.3	1700	1400	17.6	1962	960	51.0	705	580	17.7
M2	6.9	7.5	4500	4300	4.4	2450	1575	35.7	1236	863	30.1	250	204	18.4
M3	7.0	7.2	3700	3100	16.2	1800	1000	44.4	962	403	58.1	500	453	9.4
M4	7.0	8.0	6200	5900	4.8	4500	3000	33.3	1160	706	39.1	560	355	36.6

3.2. Phase-II

The objective of running Phase-II was two fold: to confirm the improvement in the waste treatment relative to Phase I, and to improve the biogas production observed for Phase I with addition of inoculum (cattle dung). And as a result, significant improvement was observed using inoculum with feedstock materials of Phase-I study for both parameters i.e. waste treatment through % removal in organic pollution load and energy recovery.

3.2.1. Organic pollution load removal (COD, BOD & TOC) with TS and pH variation

Because of the very high COD at initial stage (Day 1; 962-1962 mg/l), anaerobic treatment with biogas recovery is employed extensively as the first treatment step for this study. Anaerobic process reduces the organic pollution load and brings down BOD to 9.4- 40% and COD 39-58% from original initial value [Figure–2]. Moreover, anaerobic treatment is a slow process and typically requires long start-up periods but it can be reduce using inoculum as a seed material. Its participation in the metabolic reactions involving biogas generation was evident from reduction in substrate concentration by OPL (as COD, BOD, TOC) in all the experimental digesters studied. It appears from Table 3 that these compositions of feedstocks in digesters had the highest content of TS, TOC, BOD and COD at Day 1.

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It is generally believed that higher degradation in total solids content result in higher bacterial growth and metabolic activities. However, in the present study maximum % reduction was observed with digester M3 (16.2 %) and minimum with digester M1 (4.4 %) for TS. When the pH values of digesters are considered, it was observed that slight increase in the values after the total operation period. However, minimum pH value (6.9) in the digester M1 on Day 1, after which pH started to increase.

According to Table 3, minimum biodegradation rate related to BOD/COD ratio shown by digester M1 (0.20) where as production for all the digesters in Phase-II are summarized in the descending order as shown by M3 > M2 > M4, whereas digester M1 showed nill production of biogas. The reason may be the absence of nutrient availability and lack of water to enhance the microbial activity. The average cumulative biogas productions observed in M2 to M4 are shown in Figure 1. Similar to Phase-I, digester P3, a rapid initial biogas production was followed by a gradually increased from Day 10 to Day 40 and its may be due to degradation of soluble or easily degradable part of the organics in feed stocks was followed by hydrolysis/solubilization **[Figure–1]**. The total biogas production for digester M2, M3 and M4 was found to be 34.8 ml, 49.2 ml and 11.2 ml respectively for the entire operation period. Results indicated that after addition of cattle dung with dairy waste as inoculum resulted in a much more efficient energy producer as observed in Phase-I. Among all the four digesters from Phase I & II (P3, M2, M3 & M4), it can be concluded that both dairy industry waste product (sludge and influent) shows synergistic behavior in the presence of inoculum.

3.2.2. Biogas generation

The addition of inoculum with sludge (M1), sludge & influent (M3) and influent wastewater (M4) as co-substrates facilitated effective biogas yield due to presence of readily available carbon source, whereas only sludge & influent (M2) composition without inoculum also the part of Phase-II. The order of biogas production for all the digesters in Phase-II are summarized in the descending order as shown by M3 > M2 > M4, whereas digester M1 showed nill production of biogas. The reason may be the absence of nutrient availability and lack of water to enhance the microbial activity.

The average cumulative biogas productions observed in M2 to M4 are shown in Figure 1. Similar to Phase-I, digester P3, a rapid initial biogas production was followed by a gradually increased from Day 10 to Day 40 and its may be due to degradation of soluble or easily degradable part of the organics in feedstocks was followed by hydrolysis/solubilization (Figure 1). The total biogas production for digester M2, M3 and M4 was found to be 34.8 ml, 49.2 ml and 11.2 ml respectively for the entire operation period.

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Among all the four digesters from Phase I & II (P3, M2, M3 & M4), it can be concluded that both dairy industry waste product (sludge and influent) shows synergistic behaviour in the presence of inoculum.

[V] CONCLUSIONS

The results of this study indicate that parameters of dairy industrial waste like BOD, COD, TS and TOC show a higher rate of % reduction in values after anaerobic digestion and simultaneously potential for biogas production in waste was also noticed.

According to Phase-I result, it can be conclude that pure dairy sludge and waste water was not a potential source for gas generation at individual level. However, in Phase-II, sludge, waste water and cattle dung, in combination produced potential gas production with maximum COD removal efficiency comparative to pure feedstock’s of Phase-I. Similarly, high organic pollution load, absence of toxic chemicals and availability of large quantity of dairy industrial waste (sludge and waste water) may be considered as potential source for waste treatment and biogas production by anaerobic fermentation at the same time. Hence, the system is comparatively easy to operate and cost efficient in sustainable approach and the end products of anaerobic digestion are natural gas (methane) for energy production, heat produced from energy production, nutrient rich organic slurry, and other marketable inorganic products.

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