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Full Length Research Paper

Treatment of textile sludge using anaerobic technology

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Composite samples of sludge obtained from a textile factory were characterized for their pollution characteristics using some parameters of interest; pH, solids concentration, oxygen demand, nitrogen, phosphorus, total bacteria counts etc. The analysis revealed that the sludge has high pollution potentials and therefore needed treatment before disposal to the environment. The ratio of chemical oxygen demand, (COD) to that of biochemical oxygen demand, (BOD) was 3.08; meaning the sludge has high substrate biodegradability. Samples were subjected to mesophilic anaerobic treatment at the temperature of 35±2°C. The method achieved solids reduction of 61% total solids, 68% settleable solids and 51% volatile solids and a total bacteria reduction of 99.99%. The reduction in BOD and COD were 89% each. Nitrate and phosphate were found to reduce substantially thereby preventing eutrophication due to undesirable nutrients. The anaerobic treatment was found to have an additional benefit of producing biogas (methane and carbon (IV) oxide) which if harnessed may be used as fuel.

Key words: Textilee, mesophilic anaerobic treatment, pollution, digestion, eutrphication, sludge.

INTRODUCTION

Increasing urbanization and industrialization have resulted in a dramatic increase in the volume of wastewater produced around the world. Textile industries are large industrial consumers of waters as well as producers of wastewater. Tightening environmental standards have meant that much of these wastewaters have to be treated before it can be safely discharged. The wastewater treatment step concentrates the various pollutants in the wastewater into sludge, normally containing between 1 and 2% by weight dry solids (Priestly, 1991). Because of the dramatic increase in volume of wastewater treated large volume of sludge need to be disposed of in an environmentally safe manner. There is therefore the need to effect proper treatment to sludge before disposal or reuse.

The goal of all biological wastewater treatment systems is to remove the non-settling solids and the dissolved organic load from the effluents by using microbial populations. Biological treatments are generally part of secondary treatment systems. The microorganisms used are responsible for the degradation of the organic matter and the stabilization of organic wastes. Amongst the various practical biological treatment methods, anaerobic digestion is often the most attractive option for treatment of sludge due to the following advantages; a high BOD and COD reduction, production of energy as biogas, production of a bio-fertilizer, small production of already stabilized biological sludge that can be use as a nutrient, lower capital cost, beside all these inherent advantages, in Nigeria, climatic conditions are favourable and there is a considerable capacity to develop and optimize the process in research institute and universities.

In the recent times, efforts have been geared towards the treatment of domestic and industrial wastewaters while the sludges associated with them are merely dumped untreated into the environment. Many of the steps taken to treat wastewaters results in the concentration of pollutants into sludge (Priestly, 1991). Sludge therefore becomes unstable, putrescible and pathogenic. Sludge must therefore be treated before disposal or reuse in order to remediate our environment. This work is focused on proper treatment to sludge from a textile factory using anaerobic digestion method.

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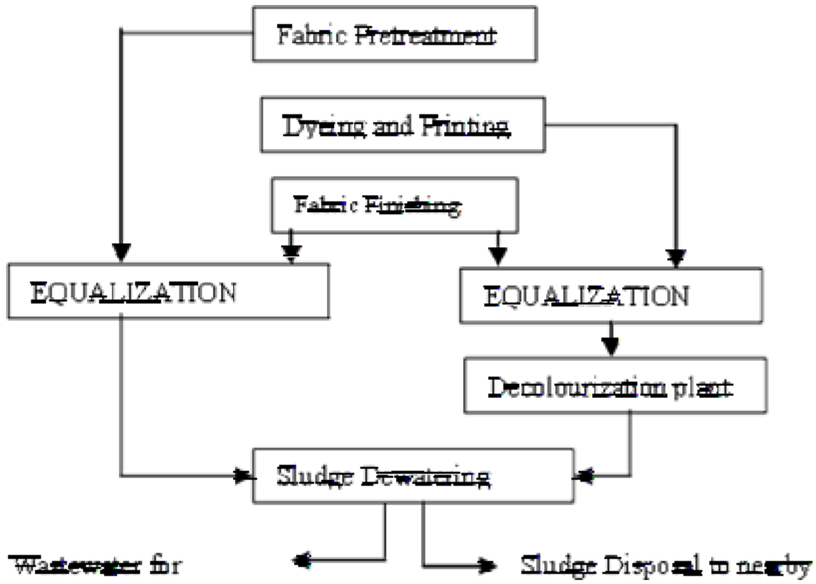

Figure 1. Wastewater flowchart of a Textile Processing factory located at Isolo Lagos, Nigeria.

Anaerobic digestion has been reported to achieve a reasonable reduction in the organic content of sludge. The main products being methane gas and carbon (IV) oxide (David, 1990; Asia, 2000).

MATERIALS AND METHODS

Industrial sludge used

The source of sludge used in this study was from textile processing factory located in Isolo, Lagos. The factory manufactures mostly cotton fabrics. The main products of the factory are superprint, guarantee-superprint and minibrocade. It consists of various departments, each of which carries out different operations and produces one type of wastewater or another. The cotton textile mill has three main departments: first, a spinning department, where the fibres are spun into yarns. Second, the weaving department, where the yarns are converted to grey fabrics. The third department is the wet processing consisting of Kier boiling, bleaching, mercerizing, dyeing, finishing and prints work. The wastes obtained here arise mainly from the Kier boiling, bleaching and the dye- house processes. The wastewater flowchart is as shown in Figure 1.

The factory is a large one and had an average annual production of 130–150 thousand metric tons and average wastewater generated per day was 3.3×10^5 L. The wastewater was known to contain acids used in desizing, dyeing bases like caustic soda used in scouring and mercerization. It also contains inorganic chlorine compounds and other oxidants e.g. hypochlorite of sodium, hydrogen peroxide and peracetic acid for bleaching and other oxidative application. Organic compounds are also present e.g. dyestuff, optical bleachers, finishing chemicals, starch and related synthetic polymers for sizing and thickening, surface active chemicals used as wetting and dispersing agents, and enzymes for desizing and degumming. Heavy metals salts are also present, e.g. copper, zinc salt and iron (III) chloride used as printing ingredients. All these wastes are passed into an effluent tank and then into a drainage system.

Sampling of sludges

Composite samples of the sludges were obtained from primary sedimentation tanks of the factory. Seven plastic bowls of 1 L capacity each were used to take samples manually over 12 h sampling period at 2 h interval starting at 7.00 a.m. and ending at 7.00 p.m. This time (period) was found to be the peak (optimum) period for work and sampling was most convenient during this period.

Composite samples were collected from each industry once a week for seven weeks and analyzed. Where analysis could not be carried out immediately, samples were preserved in a refrigerator at 4^{o}C. At this temperature, biodegradation is inhibited. The day for sample collection in the new week was different from that of the preceding week. This was done so that the total exercise might account for the cyclic and intermittent variations occurring at the work site.

Sample analysis

All samples were analysed as described in the Standard Methods for the Examination of Water and Wastewater (APHA, 1985) and Standard Methods for Water and Effluents Analysis (Ademoroti, 1996).

Treatment procedure

2 L of sludge were placed in a closed digester as shown in Figure 2. The digester was incubated at mesophilic temperature (35 ± 2^{o}C) and supplemented with nutrients to provide the needed food for the bacterial population in the sludge. Sodium hydrogen carbonate was added at concentration of 9 g/L to maintain the digestion at the optimum pH of 6.0-8.0 for anaerobic system (Dinsdale et al., 1996). Also alkalinity in the sludge was maintained at 2-5 g/L by the addition of sodium hydrogen–carbonate (Hawkes et al., 1994). Sodium, hydrogen–carbonate directly added to hydrogen–carbonate alkalinity; it does not react with carbon (IV) oxide produced during digestion. The addition of sodium hydrogen-carbonate was to disallow the pH to increase beyond 8.3 (Andrew,

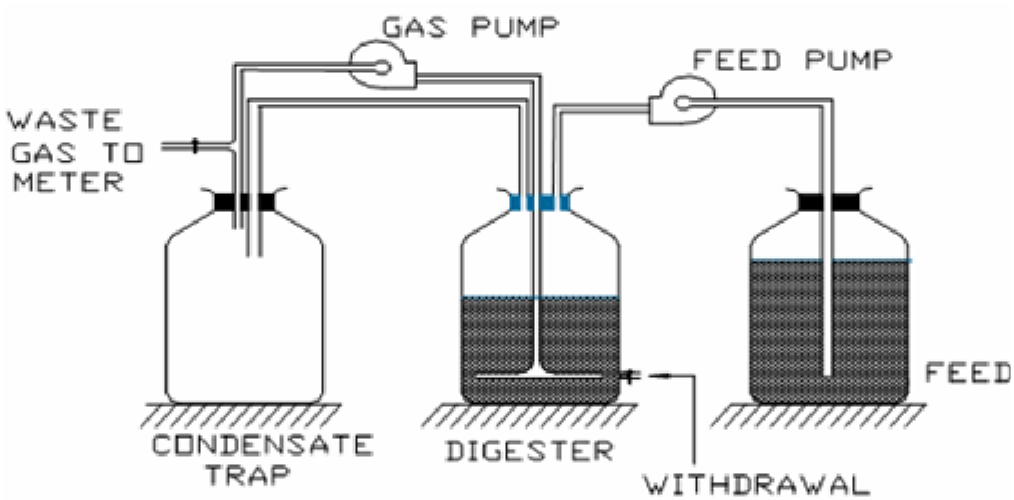

Figure 2. Laboratory Bench Scale Anaerobic Digestion Studies.

1975) and to increase digester efficiency (Barber, 1978).

A control digester was set up containing 2 L of de-ionized water instead of sludge but with all nutrients added. The mesophilic temperature (35 ± 2^oC) was maintained and at a detention time of 25 days (David, 1990). After 25 days for which digestion was deemed to have been completed, samples of well mixed digester contents were obtained for analysis. The results of analysis were as shown in Table 3.

The sludge was dewatered using a sand bed and disinfected by adding calcium oxodichloride ($CaOCl_2$) until residual chlorine was found to be between 0.2 and 0.7 mg/L (Henry and Heinke, 1989). The wet sludge was pasteurized for 30 min at 100^oC, sun dried for 3 days using a sludge drying bed and incinerated.

RESULTS AND DISCUSSION

Results

Tables 1 and 2 show the results of the characterization of fresh sludge liquor and fresh settled sludge obtained from the textile factory. Table 3 shows the results of selected parameters used to monitor the performance of anaerobic digestion of the sludge. The percentage reduction/increase in the solids content, BOD and COD values, nitrogen concentration, phosphorus content and NPK concentration of raw and treated sludges are also shown in Table 3.

Discussion

The pH values for fresh textile sludge range between 8.10 and 9.85 with the mean values at 8.91 showing it to be weakly alkaline. The specific gravity of 1.01 shows that it is slightly denser than water. Its mean moisture content was 97%. This indicated that the solid quantity in fresh textile sludge was 3%. The total, settleable solids and the volatile solids were 6.5 g/kg, 3.15 g/kg, and 4.15 g/kg respectively (Tables 1 and 2).

The BOD and COD values of the fresh sludge liquor were very high. The bacteria counts were also very high. These indicated strong pollution potentials and therefore called for treatment before reuse or disposal. The results also showed a COD:BOD ratio of 3.08. This indicated that the sludge was capable of undergoing about 50–90% substrate biodegradation (Quano et al., 1978).

Sulphate is inhibitory to anaerobic digestion process. The sulphate inhibition arises from the reduction of sulphate to sulphite and then to sulphide by some bacteria under anaerobic environments (Bilton, 1994). However, the levels of sulphate in fresh sludges were not significant. The adverse effect of sulphate if found to be significant were inhibited by the addition of hydrogen peroxide to the digester to keep the sulphide level below 0.6 mg/L (Pountney and Turner, 1979; Lin and Hsiu, 1997; Chiu-Yue and Chin-Chao, 1999) . The levels of heavy metals present in the sludges were also insignificant

Process Performance

The results of some parameters used to monitor the progress of the digestion are shown in Table 3. Lowering of pH value occurred as a result of volatile acid production during digestion process. Here high molecular weight organic contents in the sludge were converted to lower molecular weight organic acids particularly ethanoic and propanoic acids and consequently to carbon (IV) oxide. The carbon (IV) oxide also dissolved in water to give trioxocarbonate (IV) acid (H_2CO_3) (David, 1990). At low pH, the digestion medium is unfavourable to methane forming bacteria hence active digestion ceases. It has been reported that at pH below 6, unionized volatile acids become toxic to methane forming microorganisms due to the ease with which the acids pass through the cell membrane resulting in death leading to stoppage of acti-

Table 1. Characteristics of fresh sludge liquor from textile processing factory.

Sludge liquor characteristics	Unit	Mean ± SD
pH	-	8.91± 0.88
Temperature	°C	28.0 ± 1.00
Conductivity	Scm^{-1}	148.0 ± 10.58
Specific gravity	-	1.01± 0.01
Turbidity	NTU	2460.0 ±110.80
DO	mg/1	2.8±1.12
BOD_5	mg/1	550.0 ±34.32
COD	mg/1	1694.0 ±123.54
Total alkalinity	mg/1	920.0±102.01
Hydrogen carbonate alkalinity	mg/1	70.0 ±5.34
Ammonia nitrogen	mg/1	31.5 ±2.34
Nitrate nitrogen	mg/1	27.4 ±1.22
Organic nitrogen	mg/1	19.4 ±1.32
Chloride	mg/1	121.0 ±3.72
Sulphate	mg/1	123.4 ±2.78
ABS	mg/1	90.0 ±11.12
Total bacterial count.	/100ml	37×10^6

All values are mean values of triplicate determinations ± SD.

Table 2. Characteristics of fresh settled sludge from textile processing factory.

Sludge liquor characteristics	Unit	Mean ± SD
Settleable solids	mg/kg	3158 ±180.00
Moisture	%	97 ±1.50
Volatile solids	mg/kg	4150 ±210.21
Total solids	mg/kg	6500 ±552
Ash	%	36.2 ± 1.20
Total nitrogen	mg/kg	50.9 ±2.70
Phosphorous	mg/kg	5.14 ±0.91
Potassium	mg/kg	4.7 ±0.87
Oil and grease	mg/kg	198.7 ±21.12
Iron	mg/kg	0.90 ±0.19
Calcium	mg/kg	23.5 ±1.78
Magnesium	mg/kg	20.3 ±1.67
Manganese	mg/kg	nil
Copper	mg/kg	1.2 ±0.02
Cadmium	mg/kg	nil
Chromium	mg/kg	nil
Lead	mg/kg	nil
Zinc	mg/kg	3.7 ±0.65

All values are mean values of triplicate determinations ± SD.

ve digestion (USEPA, 1979). As much as 95–99% of non-viable bacterial cells were recorded after anaerobic digestion. After chlorination the remaining bacterial were destroyed.

Solids contents

The results of the amounts of solids present in raw and anaerobically treated sludge were as shown in Table 3.

Table 3. Characteristics of anaerobic digested textile sludge.

Characteristics	Before Digestion	After Digestion	% Reduction/increase
	Mean ± SD	Mean ± SD	
pH	8.91 ±0.88	5.6 ±0.32	*37.15
Temperature ^{o}C	28±1.00	31 ±0.67	10.71
Total Alkalinity, mg/1	920 ±102.01	960±0.43	4.35
Hydrogen Carbonate Alkalinity, mg/1	70±5.34	680±0.23	871
Volatile acids, mg/1	10±0.32	394.5 ±1.51	3845
ABS, mg/1	90 ±11.12	97 ±2.10	7.78
Total solids, mg/kg	6500 ±552	2535 ±123.01	*61
Settleable solids, mg/kg	3158±180.00	1011±67.20	*67.99
Volatile solids, mg/kg	4150±210.21	2034±56.32	*50.99
BOD_5 mg/l	550±34.32	60.5± 2.10	*89.00
COD, mg/l	1694±123.54	186.3 ±3.21	*89.00
NH_3 ~ N, mg/l	31.5 ±2.34	71.4 ±0.78	126.67
NO_3 ~ N, mg/l	27.4 ±1.22	1.4 ±0.11	*94.89
Org. ~ N, mg/l	19.4 ±1.32	18.9 ±0.89	*2.58
TKN, mg/kg	50.9 ±2.70	90.3 ±2.32	77.41
P_2O_5 , (Sludge liquor), mg/l	5.14 ±0.91	8.2 ±0.39	59.53
P_2O_5 , (Sludge cage), mg/kg	5.14 ±0.91	2.4 ±0.117	*53.31
Potassium, mg/kg	4.7 ±0.87	4.96 ±0.78	5.53
Total bacteria Count	**3.7×10^6**	**1.12×10^2**	***99.99**

All values are mean values of triplicate determinations ± SD
***Decrease**

Reduction in solids gave 61% TS, 68% SS and 51% VS. In all the sludges, ashes were produced in varying amounts after incineration. These ashes are useful for filling landscapes in mined areas and also in the ceramics industry for making special wares (Stocchi, 1990). The anaerobic system is therefore a good method of reducing the quantity of sludge generated by industrial processes before disposal. The reduction in the amount of sludge solids here compares favourably with 70% reduction achieved by Lane (1983), 47-72% by Kastenberg and Marchaim (1993), 60-62% VS reduction by Dinsdale et al. (1996) when they separately treated coffee waste by anaerobic mesophilic digestion. Schobar et al. (1999), reported that VS reduction under steady state conditions may reach 72% at mesophilic condition.

Methane gas produced during anaerobic digestion is combustible and may be harnessed as fuel for heating purposes and for powering industrial plants. The quantity of methane produced is closely correlated to the organic content of the sludge. It is commonly assumed that the volatile solids are a reasonable approximation of the organic matter in the sludge (Dick, 1972) and so, high reduction of the volatile solids concentration is an indication of large quantity of methane gas generated.

BOD and COD of sludge liquor

BOD and COD reductions of 89% each were achieved. This implies that anaerobic digestion is a good method of stabilizing sludge before disposal so as to alleviate pollution problems.

Nitrogen changes

The total nitrogen content was found to increase by about 77.41%, this increase in total nitrogen might be attributed to the addition of nutrient supplement (ammonium phosphate) to give reasonable nutrients to the microbial population to enable them complete the process of digestion. Organic nitrogen was found to decrease while ammonium-nitrogen increased for all sludges treated. The reason could be due to the conversion of some organic nitrogen to ammonia in the form of ammonium hydrogen carbonate (NH_4HCO_3) (Zickfosse and Karney, 1990) by some species of anaerobic bacteria. Ammonia formation generally results from the fermentation of nitrogenous compounds such as protein and urea.

It was also found that almost all of the nitrate nitrogen was reduced to ammonia by the treatment and so, nitrate nitrogen was virtually almost absent after treatment. This method of treatment is therefore efficient if nitrate removal is targeted so as to prevent eutrophication of water bodies due to the presence of nitrate.

Phosphorus in sludge

There was reduction of about 53% of phosphorus in the sludge cake while its quantity in the liquor increased by 59.53%. This may be attributed to the solubilization of phosphorus during the treatment process. Pitman (1992) confirmed that sludge-handling liquors from biological nutrients removal plants with anaerobic digesters contain high phosphorus concentrations. If phosphorus removal from sludge is the focus of treatment. The anaerobic method can give a very promising result. Sludge liquor may however be used for irrigation or agricultural purpose because, it contains considerable quantity of phosphorus after treatment.

NPK in sludge

The levels of nitrogen, phosphorus and potassium (NPK) are critical if the sludge is to be used for agricultural purposes (Sommers, 1977). The fertilizer value of sludge is detected by the percentage concentrations of NPK. A typical NPK fertilizer has a composition of 8% N, 8% P and 8% K. It may be difficult to achieve these levels of nutrients in sludge. From the results of NPK concentrations in Table 3, it was observed that the textile sludge definitely had fertilizer values; 9.7% N**,** 0.9% P and 1.4% K. If these nutrients amount were fortified by compost manure they can be used to improved soil fertility.

Conclusion

Anaerobic digestion is an attractive method for sludge treatment. It has the following advantages; considerable reductions in solids, BOD and COD, nitrates and phosphate, production of biogas, and bio-fertilizer. The method has cheap operating cost. In Nigeria, climatic conditions are favourable for the treatment method and there is a considerable capacity to develop and optimize the process.

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