DESIGN OF AN ANAEROBIC DIGESTER FOR WASTEWATER TREATMENT

Amit Dhir*

Chhotu Ram**

Abstract: *Waste-water treatment at Sant Longowal Institute of Engineering & Technology (SLIET) is being continued by using oxidation ponds. In the present studies, the waste-water was analyzed for various test values such as Bio-chemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Sulphate (SO_4) and Hydrogen-ion Concentration (pH). Based on these tests, an attempt has been made to design an upflow anaerobic sludge blanket (UASB) type digester. Calculation shows that in the prevailing conditions, 131.4 m^3 of Methane gas per day could be collected as a by–product which could be used either as a fuel or to produce approximately 125 kWh electricity. The solid residuals have potential for its use as high value fertilizer.*

Keywords: *Waste-water treatment; BOD; COD; TSS; VSS; UASB Digester; Methane gas.*

*Department of Biotechnology and Environmental Sciences, Thapar University, Patiala

**Department of Applied Sciences and Engineering, Saharanpur Campus, Indian Institute of Technology, Roorkee India

1. INTRODUCTION

Increasingly rapid urbanization and industrial developments are major source of environmental pollution [Mahajan 1998]. Urbanization has resulted in creating public health hazards by deteriorating natural water resources. Drinking water sources are often threatened by increased concentration of pathogenic organisms as well as by numerous new toxic chemicals disposed by industry and agriculture sector. In several cases, rivers and lakes have become recipients of quantities of putrescible organic substances for exceeding their natural purifying capacities resulting in the deterioration of water supplies and for reaching economic and health consequence. Pollution of water [Goyal 1996] results in change of its physical, chemical, biological and radiological quality leading to its existing, intended or potential uses. Any combination of waste-water [Parkar 1975, Matcalf and Eddy 1997] collected in municipal sewers is termed as municipal sewage. Domestic waste-water is a discharge from residential and commercial establishments whereas industrial waste-water is from industries or plants. The pollutants in the domestic waste-water arise from residential and commercial cleaning operations, laundry, food preparation and body cleaning functions and body excertions. The composition of domestic waste-water is relatively constant. Waste-water is generally treated [Trivedi *et al*.1995, Arceivala 1998] for removing undesirable component, which include both organic and inorganic matter as well as soluble and insoluble material. These pollutants if discharged directly or with improper treatment can interfere with the self-cleaning mechanism of water bodies. Various constituents of waste-water are potentially harmful to the environment and to human health. In the environment, the pollutant may cause destruction of animal and plant life, and aesthetic nuisance. Drinking water sources are often threatened by increasing concentration of pathogenic organisms as well as by many of the new toxic chemicals disposed off by industry and agricultural waste. Thus, the treatment of these wastes is of paramount importance.The collection of waste-water has been traced in early 1800's and its systematic treatment followed in early 1900's. Development of germ theory by Koch and Pasteur in latter half of 19th Century marked the beginning of new era in sanitation. From 1900 to early 1970's treatment objects were concerned with:

- Removal of suspended and floatable materials.
- The treatment of Biodegradable organisms.

- The elimination of pathogenic organisms.

From 1970 to 1980's, primary objective became based on aesthetic and environmental conditions. The main objectives of treatment continued to reduce Bio-chemical Oxygen Demand (BOD), Suspended Solids (SS), and pathogenic organisms. The removal of nutrients such as Nitrogen (N_2), Phosphorus (P) also began. These efforts resulted in

- An increase in understanding of environmental effects caused by waste-water discharge.
- A developing knowledge of adverse long term effect caused by discharge of specific constituents found in waste-water.
- The development of national concern for environmental protection.

Since, 1980's increased scientific knowledge [Jain and Garg 1997, Garg and Jain 1998] and expanded information accelerated waste-water treatment because of more focus on health concerns, related to toxic chemicals released to environment. A typical performance characteristic for various methods of sewage treatment [Manual 1993] is given in Table 1 and the flow-sheet for continuously mixed anaerobic digestion for liquid waste is shown in Figure 1.

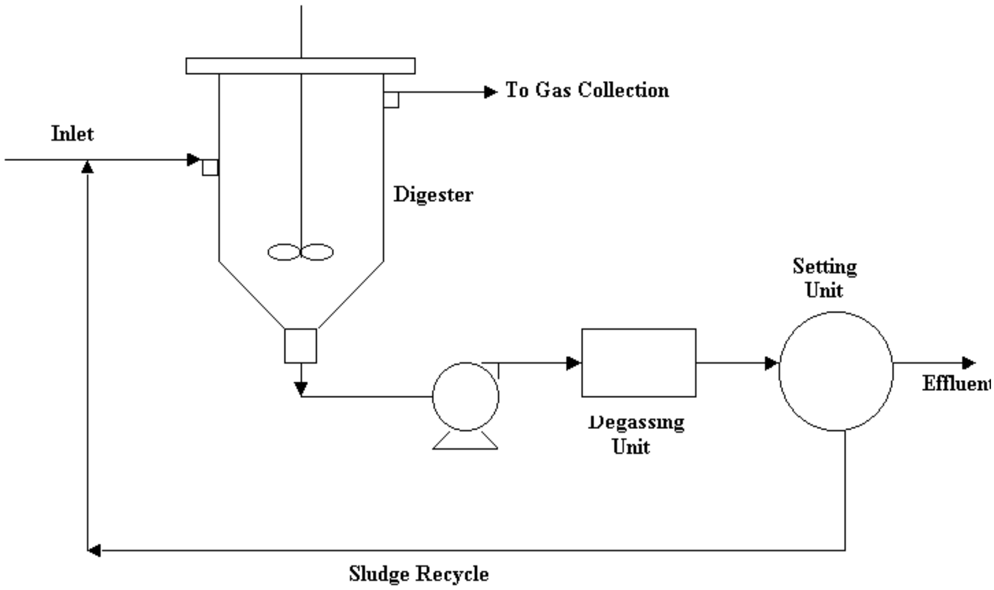

Figure 1 Flow-sheet for Anaerobic Digestion of liquid wastes

In the present studies, an attempt has been made to design an anaerobic digester of upflow anaerobic sludge blanket (UASB) type to substitute the oxidation pond for treatment of waste-water. It has the major advantages of low land and less power requirement for BOD reduction, less maintenance and low operating cost, and above all, production of biogas, which can be used as a fuel.

Table 1: Typical performance characteristics for various methods of Sewage Treatment

Parameter	**Waste stabiliza-tion ponds**	**UASB**	**Conventional activated sludge**	**Conventional trickling filters**	**Land treatment/ irrigation**
BOD, removed, %	75 – 85	75 – 85	85 – 92	80 – 90	80 – 90
Land requirement, m^2/ person	1.0 – 2.8	0.15 – 0.20	0.20 – 0.25	0.20 – 0.30	10 – 20
Process power requi-rement, kWh/ person-year	Nil	Nil	12-15	7-11	Nil
Sludge handling	Manual desludging once in 5-10 years	Directly dry on sand beds or use mecha-nical devices	First digest then dry on beds or use mechanical devices		Nil
Equipment requirement	Nil	Nil except gas collection and flaring; gas conver-sion to electricity is optional	Aerators recycle pumps, Scrapers, thickner, Digesters, dryers, gas equipment	Trickling filter arms, recycle pumps, sludge scrapes, thick-ener, digester, gas equipment	Sprinklers or drip irrigational (optional)
Effect of pop-ulation size on unit cost	Slight	Relatively little	Considerable		Slight
Operational characteristics	Simplest	Simpler than activated sludge	Skilled operation required		-------

2. EXPERIMENTAL

Samples of waste-water just pumped to oxidation pond were collected for various analysis. Sant Longowal Institute of Engineering and Technology (SLIET), Longowal with total inhabitants of ten thousand comprising of students, staff and their family members, various commercial shops and hostel mess were considered for conducting the present studies.

2.1 Analysis [Mahajan 1998, Manohar 1999**]**

Following tests of SLIET waste-water were conducted:

Bio-chemical Oxygen Demand (BOD): BOD refers to quality of oxygen required by bacteria and other micro organism in bio-chemical degradation and transformation of organic matter under aerobic condition. The standard method of measurement of dissolved oxygen (DO) content of the sample before and after five days incubation at 20^{O}C was used for calculation of BOD.

Chemical Oxygen Demand (COD): COD represents the oxygen requirement of a sample for oxidation of organic and inorganic matter. COD does not require five days procedure as required for BOD but this test does not differentiate between biodegradable and bio-inert materials. This test was conducted by adding potassium dichromate along with sulphuric acid and a catalyst followed by titration against Mohr's salt. Standard method for calculation of COD was then used.

Total Suspended Solids (TSS): Total solids are the residues that include both dissolved and suspended solids. Centrifuge was used for filtration of the sewage water, followed by evaporation and drying for measuring total dissolved solids. Suspended solids were determined by substracting dissolved solids from total solids.

Volatile Suspended Solids (VSS): VSS get produced as a result of BOD removal. Total solid content is the sum of dissolved, suspended and these newly formed solids.

Sulphate (SO_4^{-2}) Test: High sulphates may come from original water supplies or from infiltration of brackish ground water where sewers pass through such areas. The sulphides formed from sulphate can lead to corrosion and other problems because of its toxic nature. This test was conducted using barium chloride as usual reagent and following the standard procedure.

Hydrogen-ion-Concentration (pH): It is as important as the total solid content for the sewage and temperature for ecological studies as a whole. Acidic wastes are corrosive to both metallic and concrete structure. Besides being toxic to the aquatic life they react with the natural alkalinity of the water, thereby increasing the carbonate hardness and thus rendering it unfit for future uses in laundry or boilers. The pH value was measured by using electronic pH meter.

Standard values [9] of some of these parameters and those of SLIET waste-water are given in Table 2 and Table 3 respectively.

2.2 Design of an anaerobic digester [Manohar 1999]

In the present studies, design of an upflow anaerobic sludge blanket (UASB) type digester has been undertaken for treatment of SLIET waste-water. The USAB design is tailor made to suit the waste-water characteristics given in Table 2.

Total population at SLIET = 10,000

Average flow rate of waste-water = 1500 m^3/day

Let BOD removal efficiency (η) = 80%

New volatile suspended solids (NVSS) produced in BOD removal

= Yield coefficient x BOD x η

= 0.1 x 300 x 0.8

= 24 mg/L

Non degradable residue = VSS (1 – 0.4)

(The non-degradable residue of the VSS coming in the inflow assuming 40% of the VSS are degraded and residue is 60%)

= 270 (1 – 0.4) = 162 mg/L

Ash received in inflow = (TSS – VSS) mg/L

= 400 – 270 = 130 mg/L

Sludge produced = 24 + 162 + 130 = 316 mg/L

= 0.316 kg/m^3

Total sludge produced = 1500 x 0.316 kg/day

= 474 kg/day

Table 2 Various test values of SLIET Waste-water

Sr. No.	Test	Value
1.	BOD, mg/L	300
2.	COD, mg/L	450
3.	TSS, mg/L	400
4.	VSS, mg/L	270
5.	pH	7.7
6.	SO_4 , mg/L	85

Reactor dimension = (Total flow, m^3 per day) / (upflow velocity, m per day)

= ($1500m^3$ per day) / (0.5 m/h)

= 125 m^2

(Upflow velocity was calculated using the values of solid retention time (SRT) and Hydraulic retention time (HRT) used elsewhere [Manohar 1999].

If length of rectangular reactor = 15m

Then, width = 125 / 15 = 8.333 m

Depth = 4.8 m

Check for organic loading

Volumetric organic loading = COD load / volume of reactor

= 450 mg/L x 1500 m^3 per day / 15 x 8.333 x 4.8 m^3

= 1.125 kg COD/ m^3 day

Acceptable Limit = 1 – 3 kg COD / m^3 day

Assumptions

Solid retention time (SRT) at given temperature = 30 days

Hydraulic retention time (HRT) = 8 – 10 hrs at average flow

Average concentration of sludge in the blanket = 60 kg/m^3

Full depth of reactor for treating low BOD municipal sewage = 4.5 to 5 m (say, 4.8m)

COD Removal and Methane gas production

Total COD removed = 80% of incoming load

= 0.80 (0.450 x 1500) kg per day

= 540 kg per day

Sulphate removal = 0.80 (0.085 x1500) kg per day

= 102 kg per day

COD available for Methane gas production = 540 – 102 = 438 kg per day

Theoretically, Methane gas produced at 25^{O}C = 300 L/kg COD removed

Therefore, total Methane gas produced per day = 0.300 m^3/ per kg x 438 kg per day

= 131.4 m^3 per day

Practically observed Methane gas leaving as dissolved in effluent

= 0.028 m^3 per m^3 effluent volume per day

Therefore, Methane gas leaving = 0.028 x 1500 = 42 m^3/ per day

Hence, usable Methane = (131.4 - 42) = 89.4 m^3/ per day

= 89.4/ 540 m^3/ kg COD

= 0.165 m^3/ kg COD

Theoretically, it is known that 1 m^3 bio-gas with 75% Methane content produce 1.4kWh electricity.

Thus, 89.4 m^3 bio-gas per day = 1.4 x 89.4 kWh electricity

= 125.16 kWh electricity

Table 3 Design results of UASB Digester based on SLIET Waste-water

Sr. No.	Particular	Value
1.	Total sludge produced, kg/day	474
2.	Area of Reactor, m^2	125
3.	Length of Reactor, m	15
4.	Width of Reactor, m	8.333
5.	Depth of Reactor, m	4.8
6.	Volume Organic Loading, kg COD/ m^3 day	1.125
7.	Total COD removed, kg/day	540
8.	COD available for Methane production, kg/day	438
9.	Useable Methane, m^3/ kg COD	0.165
10.	Electricity production, kWh	125.16

Table 4 Standard values of parameters as per schedule VI of Environment (Protection) third Amendment Rules, 1993.

Sr. No	Parameter	Standards		
		Inland surface water	Public Sewers	Land for irrigation
1.	Suspended solids, mg/L, max	100	600	200
2.	pH value	5.5 – 9.0	5.5 – 9.0	5.5 – 9.0
3.	BOD (5 days at $20^{O}C$), mg/L, max	30	350	100
4.	COD, mg/L, max	250	--	--
5.	Sulphide as (S), mg/L, max	2.0	--	--
6.	Oil & Grease, mg/L, max	10	20	10

3. DISCUSSION AND CONCLUSION

SLIET waste-water treatment, which is presently being done using oxidation pond, has been creating foul smell in its vicinity. It not only requires large space but also looses a fairly good amount of bio-gas, which could have been produced as a byproduct and used as a fuel. Table 3 shows the various test values of SLIET waste-water, required for the design of UASB digester. The temperature range of more than 20ºC and sufficient flow fluctuation are the other characteristics available for such design. It has been found that with a population of about 10,000 at SLIET, average flow rate of waste-water production is 1500 m^3/day. As shown earlier with the consideration of 80% efficiency of BOD removal, the total sludge produced is 474 kg/day, sufficient for further performance of UASB digester. The reactor/ digester area with these values comes as 125 m^2. The other dimensions like width and depth are well within the operatable limits if the length of such reactor is considered as 15m. If 80% efficiency of COD removal is considered, the available COD for Methane gas production after sulphate removal comes as 438 kg/day. This can produce 131.4 m^3 of Methane gas per day. Finally, considering the losses etc in the process, the usable Methane gas per day is 89.4 m^3, which in turn is sufficient to produce 125.16 kWh of electricity. It is worth to mention that only a part of the bio-gas formed in the UASB is presently available for energy purpose, the rest stays as dissolved in the waste-water and pass out with the effluent. More efforts are required for further improvement of Methane recovery and hence more energy production. BOD removal of 75-85% makes the UASB a good and economical form of intermediate treatment, such as that required prior to land irrigation in India. Its low operating power cost makes it worthwhile to consider. If power failure occurs, the process does not suffer, as it is already anaerobic in nature. Provision of captive power supply for only initial pumping of raw sewage can keep the whole plant operational at all time. This is a great advantage in many parts of India where regular power cuts occur. Moreover, with minimal equipment, their repair and maintenance is also simplified. The other major advantage of UASB is its low land requirement; a duckweed pond and fish pond could also be established for its safe and economic viability. Thus, it can be concluded that UASB is feasible at SLIET, in terms of saving land, avoiding foul smell, producing energy and providing fish etc to its population at a cheap rate.

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