Buoyant Filter Bio-Reactor (BFBR)–a novel anaerobic wastewater treatment unit

Soosan J. Panicker, M. C. Philipose and Ajit Haridas

ABSTRACT

The Buoyant Filter Bio-Reactor (BFBR) is a novel and very efficient method for the treatment of complex wastewater. Sewage is a complex wastewater containing insoluble COD contributed by fat and proteins. The fat and proteins present in the domestic sewage cause operational problems and underperformance in the Upflow Anaerobic Sludge Blanket Reactor, used now for treating sewage anaerobically. The biogas yield from the BFBR is 0.36 m^3/kg COD reduced and the methane content was about 70–80%. Production of methane by anaerobic digestion of organic waste had the benefit of lower energy costs for treatment and is thus environmentally beneficial to the society by providing a clean fuel from renewable feed stocks. The BFBR achieved a COD removal efficiency of 80–90% for an organic loading rate of 4.5 kg/m^3/d at a hydraulic retention time of 3.25 hours. The effluent COD was less than 100 mg/l, thus saving on secondary treatment cost. No pretreatment like sedimentation was required for the influent to the BFBR. The BFBR can produce low turbidity effluent as in the activated sludge process (ASP). The land area required for the BFBR treatment plant is less when compared to ASP plant. Hence the problem of scarcity of land for the treatment plant is reduced. The total expenditure for erecting the unit was less than 50% as that of conventional ASP for the same COD removal efficiency including land cost.

Key words | activated sludge process (ASP), BFBR, COD, complex wastewater, hydraulic retention time (HRT)

Soosan J. Panicker
Department of Civil Engineering,
T.K.M. College of Engineering,
Kollam 691005,
India
E-mail: [illegible]

M. C. Philipose
T.K.M. College of Engineering,
Kollam 691005,
India
E-mail: [illegible]

Ajit Haridas
National Institute for Interdisciplinary Science and Technology,
CSIR,
Thiruvananthapuram 695019,
India
E-mail: [illegible]

INTRODUCTION

New anaerobic technology extends the benefits of anaerobic treatment with high-rate anaerobic reactors to low and medium strength effluents, thus allowing treatment cost reduction. High-rate reactors enable efficient removal of COD at low hydraulic retention times. The principle of the high-rate reactor is the decoupling of the biomass retention time from the hydraulic retention time (Stronach *et al.* 1986; Zeeman *et al.* 1997). The high-rate reactors function efficiently only when COD in the wastewater is in dissolved form. The BFBR is a high-rate anaerobic reactor designed for the treatment of complex wastewater. Domestic sewage is a complex wastewater. The basic processes of anaerobic degradation of complex waste can be classified into solubilization and hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The rate-limiting step in treating complex waste is hydrolysis and solubilization, whereas, for soluble wastes usually methanogenesis, particularly aceto-clastic methanogenesis, is the rate-limiting step in well-functioning anaerobic reactors (Hwu *et al.* 1998; Lalman & Bagley 2001; Yu & Fang 2001). Hence in the treatment of complex wastewater, insoluble substrates should be retained in the reactor sufficiently long for efficient hydrolysis and solubilization. In other words, the SRT (solids retention time) must be decoupled from HRT (hydraulic retention time). The BFBR attempts to enhance loading rate and treatment efficiency of complex wastewater in anaerobic

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reactors by decoupling SRT from HRT (Manilal & Haridas 2000; Haridas *et al.* 2002, 2005). The paper reports the performance of BFBR for the anaerobic treatment of a complex sewage.

MATERIALS AND METHODS

Figure 1 shows the laboratory model BFBR used for the study. It comprises: (a) a lower chamber (active volume 6.5 l), where sludge and sewage are mixed with a gas aspirating mechanical stirrer, (b) co-current horizontal tube settler that separates and recycles sludge to the lower chamber by means of a peristaltic pump, and (c) a filter chamber (5 cm × 4 cm section) containing a 7 cm deep filter bed made of expandable polystyrene beads (0.5–1.0 mm). The filter chamber also contains wires across its section to break up the bed when it is fluidized during backwash. The filter bed floats and hence is called "Buoyant Filter". A steel wire mesh (0.3 mm) retains the buoyant filter in position inside the filter chamber, d) an upper chamber of 2.9 l to collect filtered effluent and gas generated in the system, e) an effluent overflow nozzle with siphon break, f) an automatic backwash system working on the inverted siphon principle used for gas discharge, g) wet gas flow meter for biogas measurement.

Initially, about 30% of the lower chamber volume was filled with sludge taken from a biogas plant treating canteen waste. Synthetic sewage was specially prepared to simulate the characteristics of sewage with regard to its behavior

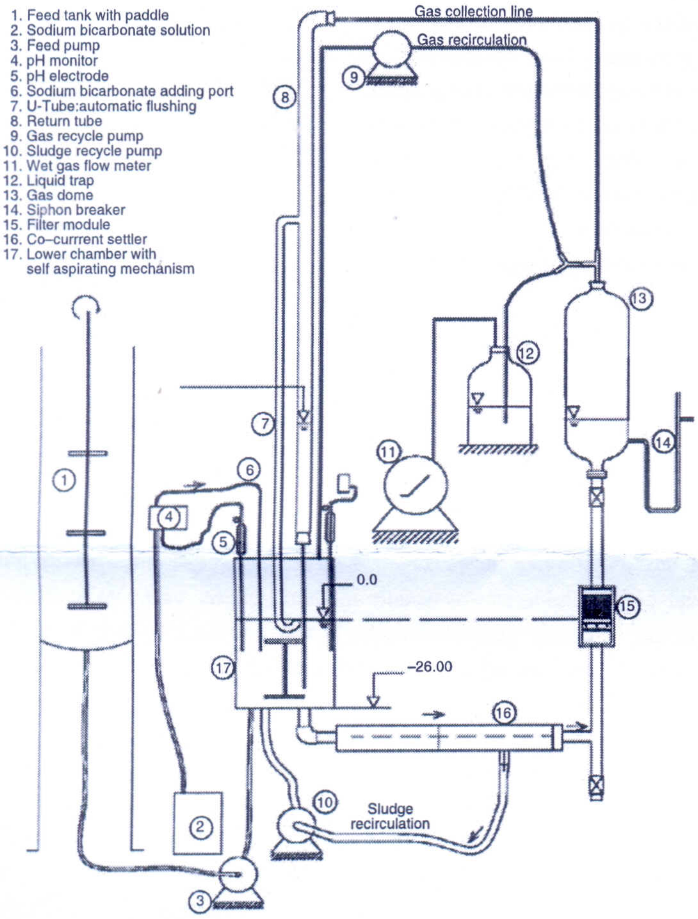

Figure 1 | Schematic set up of BFBR.

during anaerobic treatment. The composition of the synthetic sewage was tapioca powder 0.55 g/l, NH_4Cl 0.05 g/l, $(NH_4)_2HPO_4$ 0.04136 g/l, $NaHCO_3$ 0.84 g/l, milk 1.1 ml/l, sodium stearate 2.5 ml/l. The synthetic sewage has characteristics similar to municipal sewage (COD 1,060 mg/l, TSC 1,430 mg/l, SS 530 mg/l, DS 896 mg/l, fat and oil 38.5 mg/l, TP 7 mg/l TN 46 mg/l NH_3—N 39 mg/l). The sewage was stored in a tank and was kept well mixed by a paddle mixing. The COD of the feed gradually reduced due to start of bio-degradation in the feed tank and the average COD of feed entering the reactor was 600 mg/l. A key component of the BFBR is the granular filter bed, which retains sludge and wastewater solids (Elmitwalli *et al.* 2000). The filter bed is kept free from choking and excessive pressure drop by intermittent reverse fluidization, which backwashes retained solids in to the reactor mixed liquor, an added advantage of this filter. The backwashing of filter bed is accomplished by a periodic release of gas accumulated in the reactor, thereby avoiding extra pumping system and power consumption.

The filter bed is made from non-degradable expandable polystyrene balls of 0.5–1.0 mm size having specific surface area 4,200 m^2/m^3, porosity 35.8%, void ratio 0.56, specific gravity 0.15 and filter bed depth of 7.0 cm. The filter bed enables the BFBR to decouple both solids and biomass retention time from hydraulic retention time, while providing mixed i.e., high mass-transfer conditions, in the active lower chamber. The liquor in the reactor is mixed by the gas aspirating stirrer mechanism. The HRT for the BFBR is calculated on the basis of active volume of reactor (6.5 l), was varied between 15 hours to 3.25 hours. Increase in organic loading rate was affected by increasing hydraulic loading rate (10.4–47.5 l/d) Table 1. The average biomass production in the reactor was estimated as 0.37 g/d and yield of 0.013 g VSS/g COD. The biomass produced in the filter bed was found as 0.01 g/d maximum. The parameters monitored regularly were pH, alkalinity, total VFA, gas production, COD, and filtration efficiency. Reactor MLSS and microbiological examinations were done occasionally. Total biogas production was recorded with a wet-gas flow meter. Alkalinity and VFA of the reactor liquor and effluent were estimated titrimetrically (Anderson & Yang 1992). COD, SS, NH_3-N were determined as per Standard Methods (APHA 1995).

The filtration characteristics of the buoyant filter bed during the filtration anaerobic reactor MLSS are difficult to determine, as these are highly dependent on the nature of the sludge. While sludge has good settle-ability at most times, there are occasions when highly bulking sludge forms, the reasons for which are not clear. Under bulking conditions, not more than 1 cm of clear liquor is seen during quiescent settling tests with a 25 cm mixed liquor column. The filter is rapidly choked during episodes of bulking and required very frequent backwash. However, this decreases the filter productivity and filter area required becomes unacceptably large. Improvement in filter run can be achieved by limiting solids loading on the filter bed. The horizontal tube settler was used to separate sludge from the mixed liquor and recycle it back to the reactor. The horizontal tube settler with co-current flow of settled sludge and clarified liquor has a high sludge recirculation rate and enables separation of bulking (very slow settling) sludge. The horizontal settler removes about 40–50% of the MLSS from the reactor liquor even under bulking-sludge conditions (Table 2). The filter solids removal performance at solids areal loading 1.5 kg SS/m^2/h and filter velocity

Table 1 | Average performance of BFBR at various hydraulic loading rates

Hydraulic Loading rate (l/d)	HRT (h)	Influent average COD (mg/l)	Effluent COD (mg/l)	COD removal (%)	Solid removal (%)	Effluent turbidity (NTU)	Gas production (l/d)
10.4	14.9	600	132	78	95	20	1.8
14.4	10.8	600	102	83	96	20	2.0
19.8	7.9	600	75	87	94	20	2.8
25.9	6	600	108	75	95	20	4.6
29.9	5.2	600	91	85	94	22	6.4
47.5	3.25	600	87	80	96	26	8.95

Table 2 | Solid removal in Horizontal settler

Influent solid (mg/l)	Effluent solid (mg/l)	Solid removal (%)
1,648	1,140	31
1,748	944	45
1,505	800	46.8
1,689	847	50

1.87 m/h was greater than 90–95%. The filter backwash interval was set between 20–24 minutes and filter pressure drop was less than 5 cm.

RESULTS AND DISCUSSION

The reactor was operated continuously for 3months.The average influent feed COD was 600 mg/l. At the end of the period, the effluent COD was less than 100 mg/l and turbidity was 20–25 NTU. The total volatile fatty acid in the effluent was less than 1.0 meq/l (65 mg/l as acetic acid). The maximum gas yield was 0.36 m^3/kg COD reduced. The maximum organic loading rate was 4.5 kg/m^3.d and COD removal efficiency was 80–90% at HRT 3.25 h. The VFA to alkalinity ratio in the digester was less than 0.4 during stable condition. After achieving stable methanation, the total VFA concentration in the reactor was less than 2.0 meq/l (132 mg/l as acetic acid). Table 1 shows the average performance of the reactor at different loading rates. Figure 2 shows the performance history of the reactor. COD removal efficiency was greater than 85% at a hydraulic loading rate of 47.5 l/d (organic loading rate of 4.5 kg/m^3/d). The effluent was clear, without characteristic anaerobic odor, the residual COD at most times was less than 100 mg/l.

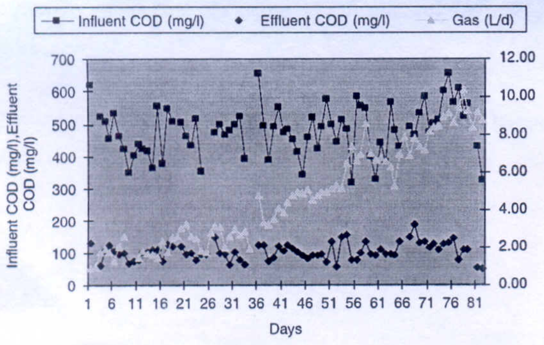

Figure 2 | Performance of the BFBR on sewage: COD and gas production.

CONCLUSIONS

In conclusion, the following has been noted.

- The BFBR can be used to treat sewage without primary treatment.
- 4 h HRT is sufficient to achieve adequate COD removal.
- The BFBR can produce low turbidity treated effluent (as in activated sludge).
- Sludge with very poor ability to settle (bulking sludge) can form in the BFBR at certain times and it affects filter productivity by increasing solids loading on filter.
- Solids loading rate on filter can be reduced using a co-current horizontal tube settler to separate bulking sludge.

Comparison of BFBR with conventional activated sludge process

The expenditure for erecting BFBR is roughly one third of that required for conventional activated sludge process (ASP) for the same BOD removal efficiency including land cost. The area of land required for the unit is very less when compared with that required for ASP. Hence the scarcity of land for treatment plant can be rectified by replacing the conventional ASP with BFBR. The operation charge of BFBR is less when compared to ASP. The anaerobic technology used in BFBR is proved as a novel and efficient technology alongside other anaerobic units such as UASB, Packed Bed and Fluidized Bed Fixed Film Reactor.

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