Iran. J. Environ. Health. Sci. Eng., 2010, Vol. 7, No. 2, pp. 129-136

HIGH RATE ANAEROBIC TREATMENT OF COFFEE PROCESSING WASTEWATER USING UPFLOW ANAEROBIC HYBRID REACTOR

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Received 15 July 2009; revised 30 January 2010; accepted 20 Feburary 2010

ABSTRACT
The present study is an attempt to treat the coffee processing wastewater using upflow anaerobic hybrid reactor which offers the advantage of both suspended and attached growth anaerobic reactor systems. Upflow anaerobic hybrid reactor with a volume of 19.5 L was operated at 24 h hydraulic retention time. After the startup period, the reactor was evaluated by operating at different hydraulic retention times of 24, 18, 12 and 6 h. The reactor performed better at HRT=18 h with short period of time. At 18 h retention time, reduction of chemical oxygen demand, biochemical oxygen demand and total solids were 61.0, 66.0 and 58.0 per cent, respectively, with organic loading rate of 9.55 kg/m^3/day. The maximum quantity of biogas produced were 840, 775 and 430 L/kg of TS, BOD and COD removal, respectively, with the methane content of 60.7% at HRT=18 h. The finding of the study helps to design low cost and compact onsite treatment systems with a very short retention period.

Key words: Coffee processing wastewater, Upflow anaerobic hybrid reactor, Chemical oxygen demand, Biochemical oxygen demand, Organic loading rate

INTRODUCTION
Coffee, which belongs to the genus *Coffea* of rubiaceae family, is one of the most popular beverages consumed throughout the world. India ranks sixth in the world in coffee production. The average annual production is 0.291 million tones from an area of 0.354 million hectares of land. Both Arabica and Robusta varieties of coffee is cultivated mainly in the hilly tracts of South India and Northeastern states.

Coffee is processed either by wet or dry method. Wet method of processing results in a coffee of superior quality compared to dry method. Presently in India, around 75–80 % of Arabica and 15-20% of Robusta are processed by wet method. This coffee processing method needs mechanical removal of pulp with the help of water and due to this, a considerable amount of wastewater is generated (Murthy *et al.,* 2003). The resultant coffee processing wastewater (CPWW) is acidic and rich in total suspended and dissolved solids which are biodegradable. If the wastewater emanating from these operations are discharged into the natural water bodies without treatment, it will pollute the receiving water body (Shanmukhappa *et al.,* 1998).

The high rate reactor, most widely used for the treatment of several types of wastewaters is Upflow Anaerobic Sludge Blanket (UASB) reactor developed by Lettinga (2001). The upflow anaerobic hybrid reactor (UAHR) configuration has combined the advantages of both UASB and Upflow Anaerobic Filter (UAF) while minimizing their limitations and the reactor is efficient in the treatment of dilute to high strength wastewater at high Organic Loading Rates (OLR) and short Hydraulic Retention Time (HRT).

Anaerobic digestion has been applied with different degrees of success to the treatment of liquid and solid wastes from the coffee processing units (Kostenberg and Marchaim, 1993). In this study, the reactor was studied for its efficiency in treatment of coffee processing wastewater under different hydraulic retention times (HRT) and organic loading rates.

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MATERIALS AND METHODS

Sample collection

The study was conducted in the laboratory of Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. Coffee processing wastewater was collected from the coffee processing units located in Thandikudi, Dindigul (District), Tamil Nadu. A part of these samples were prepard for those analyses which were considered to be done immediately. The rest of the collected CPWW was stored in the cold room at 4˚C. The wastewater was analysed for pH, EC, Total Solids (TS), Total Dissolved Solids (TDS) , Dissolved Oxygen (DO), COD and BOD, employing methods detailed in Standard Methods (APHA, 1992).

Treatment of CPWW using UAHR

Design details of UAHR

A laboratory scale upflow anaerobic hybrid reactor was made of 4 mm thick clear acrylic sheet to study the biomethanation potential of CPWW. The volume of the reactor was 19.25 L. The reactor had a Gas-Liquid-Solid [GLS] separator installed at the top of the reactor. The hybrid reactor is a modified version of the UASB system with PVC frill sheet as the solid support and combines the merits of the UASB and fixed film reactors (Lettinga, 2001). The reactor details along with dimensions are given in Table 1 and the schematic of UAHR is illustrated in Fig.1. The wastewater from the container was pumped into the reactor through inlet by a peristaltic pump (Watson Marlow).

Reactor seeding

The reactor was seeded with the anaerobic consortia developed in the laboratory through enrichment of coffee pulp and coffee effluent. Initially about 50 % of the reactor volume was filled with anaerobic consortia, followed by the addition of fresh effluent to 100 % volume of the reactor. At periodic interval of three days, 1/3rd of the seeding material was removed and replaced with fresh effluent; this was repeated for four times. Subsequently 2/3rd of the seeding material was removed and replaced with fresh effluent at three days interval and repeated for four times. This was done for proper acclimatization of anaerobic consortia with coffee processing wastewater. In UAHR, the anaerobic consortia was immobilized in PVC packing medium.

Startup

The reactor startup is very important as it has an impact on continuous and efficient operation without any system failure. During the initial startup of the reactor, the CPWW was fed continuously with HRT of 24 h.

Process optimization of UAHR

The reactor was operated at different HRTs as 24h, 18h, 12h and 6h and the biomethanation potential for the reactor was assessed in terms of BOD and COD reduction, methane and total gas production. The reactor was run at least for 5–6 h retention time after reaching steady state condition of each HRT. Steady state condition was judged by stable gas production and constant COD and BOD of the effluent (Patel and Madamwar, 2002).

Table 1: The dimensions of the UAHR systems

Particulars	UAHR
Total height of the reactor	125 cm
Height of the bottom portion of the reactor	100 cm
Height of the GLS, housing and gas collector assembly	25 cm
Height of the GLS assembly	18 cm
Cross section of sludge bed	10x10 cm
Cross section of the gas collector assembly	23x23 cm
Volume of the digester	19.25 l
Settler volume [above the bottom portion of reactor-c/s.10X10 cm^2]	9.650 l
The slope of the GLS settler bottom [inclined wall]	53˚
No. of acrylic mesh kept in the hybrid reactor	2
Diameter of holes in acrylic mesh	1 cm

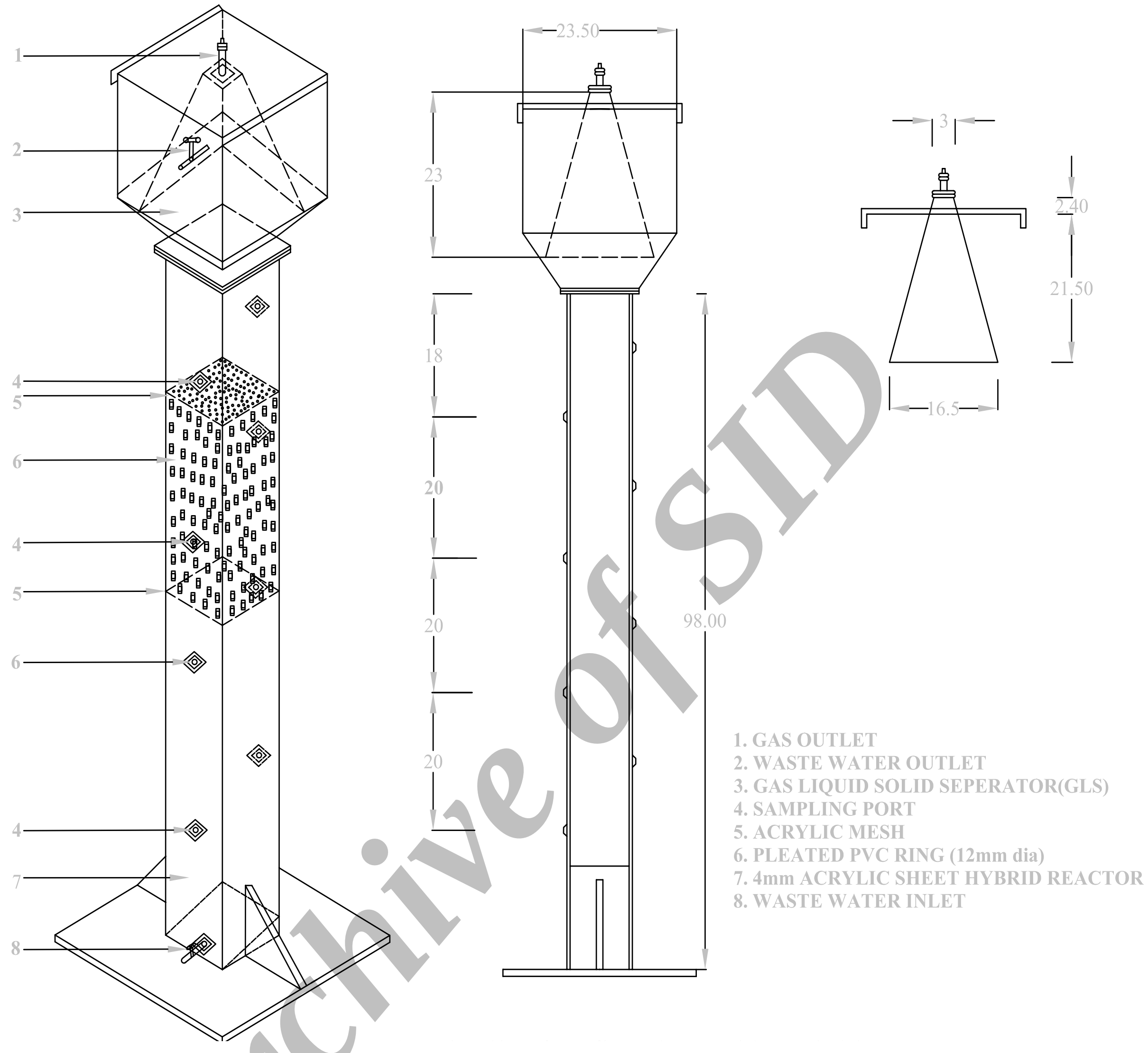

Fig. 1: Design details of UAHR

Analytical methods

The influent and treated effluent was collected at the end of each HRT. The pH, EC, TS, COD and BOD of collected samples were analysed according to the Standard Methods of APHA (1992).

Biogas production

The biogas was measured by using water displacement method and methane percentage was measured by gas chromatography, with thermal conductivity detector (TCD) having Porapak Q column by setting the oven temperature at (80-100) °C, injector temperature at (100-200) °C, detector temperature at 120 °C and using nitrogen as carrier gas at a flow rate of 30 mL/ min.

RESULTS

Characterization of CPWW

The characteristics of the CPWW used for experiments are presented in Table 2. The wastewater had a pH range of 3.88 to 4.21 and the EC ranged from 0.96 to 1.20 µm/cm^2. The total dissolved solids and total suspended solids were 1130 to 1380 and 2390 to 2820 mg/L, respectively.

The total solids content was 3520 to 4200 mg/L. The dissolved oxygen content of the wastewater was very low with a value of 2.0 to 2.6 mg/L. The BOD and COD were 3800 to 4780 and 6420 to 8480 mg/L, respectively. The total organic carbon content of the wastewater was ranging from 0.36 to 0.48 percent. The total nitrogen, phosphorus and potassium content of the wastewater ranged from 125.8 to 173.2, 4.4 to 6.8 and 20.4 to 45.8 mg/L, respectively. The calcium and magnesium content of the wastewater were 67.8 to 92.0 and 42.5 to 62.1 mg/L, respectively. The chloride and sodium were found to be in the range of 25.2 to 46.8 and 7.8 to 13.8 mg/L, respectively.

Treatment of CPWW using UAHR

Startup process

The UAHR was fed after seeding with the coffee processing wastewater and (HRT of 24) h was followed during the startup period. The variation in different parameters of coffee processing wastewater during startup period was observed. During the second day of the startup period, the COD removal efficiency was 25.53 % which gradually increased and reached a maximum of 70.58 % at the end of the startup period. Similarly the BOD_5 removal efficiency was 33.3 % on the second day and increased to 71.87 % at the end of the startup period. In the treated effluent, the pH level increased from 4.6 on the second day to 6.38 at the end of startup period. The TS removal efficiency was 26.31% on the second day and increased to 64.61% at the end of startup period. The biogas production was increased from 0.045 L/d at initial to 1.350 L/d at the end of startup period, which indicated the steady state condition of the process. During startup period, the maximum total quantities of biogas production were 535.71, 489.13 and 281.25 L/kg of TS, BOD and COD removed, respectively. The methane content was fluctuated initially and steadily increased to 60.2 % at the end of start up period.

Table 2: Characteristics of coffee processing wastewater (CPWW)

Parameters	Concentration
Physical properties	
Total dissolved solids (mg/L)	1130-1380
Total suspended solids (mg/L)	2390-2820
Total solids (mg/L)	3520-4200
Physico-chemical properties	
pH	3.88-4.21
Electrical Conductivity (dS/m)	0.96-1.20
Dissolved Oxygen (mg/L)	2.0-2.6
Biochemical oxygen demand (mg/L)	3800-4780
Chemical oxygen demand (mg/L)	6420-8480
BOD: COD ratio	0.56-0.59
Total organic carbon (%)	0.36-0.48
Nitrogen (mg/L)	125.8-173.2
Phosphorus (mg/L)	4.4-6.8
Potassium (mg/L)	20.4-45.8
Calcium (mg/L)	67.8-92.0
Magnesium (mg/L)	42.5-62.1
Chloride (mg/L)	25.2-46.8
Sodium (mg/L)	7.8-13.8

Process optimization

Subsequent to the startup period, process optimization was carried out by operating at different HRTS of 24, 18, 12 and 6 h. For each change in HRT, an initial unstablity was noticed in the COD and BOD removal efficiency; but the stability was attained after few days periods of each HRT. Table 3 shows removal of COD, BOD and TS as influenced by different HRTs and COD loading rates. Among the different HRTs, 24h provided the maximum efficiency in reduction of pollution load of BOD, COD and TS to a level of 66.0%, 61.0% and 58.0 %, respectively, with a COD loading rate of 7.01 $kg/m^3/day$. The reactor efficiency followed a decreasing trend with HRT.

Among the different HRTs, the reactor exhibited maximum efficiency during 24h and 18h and minimum during 12h and 6h. The average steady state COD removal efficiency was high in the range of 70% at HRT=24h, followed by 61%, 52% and 46 % at HRT=18h, 12h, 6h, respectively. The average steady state BOD_5 removal efficiency was high (71 %) at HRT=24h, followed by 66 % at HRT=18h, 59% at HRT=12h and 54 % at HRT=6h. The average steady state TS removal efficiency was high (64%) at HRT=24h, followed by 58%, 49% and 42% at HRT=18h,12h,6h, respectively. The maximum biogas production per kg of BOD, COD and TS removed at

HRT=18h and 12h were 775, 430, 840 and 620, 390, 690 L, respectively. At HRT=18h and 12h, the maximum biogas production of 2.62 and 2.91 L/d were recorded, respectively, with the methane content of 60.7% and 59.4 %.

DISCUSSION

Characterization of CPWW

The pH of the CPWW ranged from 3.88 to 4.21. The acidic pH is due to the presence of organic acids in berry skin and pulp. It is in accordance with the findings of Hue *et al*. (2006). They reported that the pH ranged from 3.5 to 4.5 in wastewater from the coffee fruits processing. The electrical conductivity of the CPWW ranged from 0.96 to 1.20 µm/cm^2, which could be due to the presence of nutrients. It is in accordance with the findings of Matos *et al*. (2001). They reported that the EC ranged from 0.932 to 1.069µm/cm^2 in the wastewater from the coffee fruits processing.

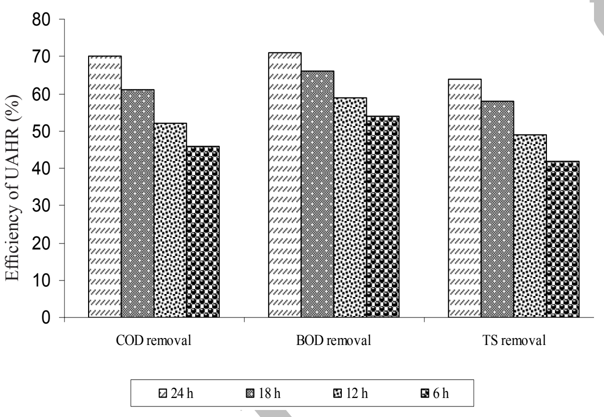

Fig. 2: Effect of Hydraulic Retention Time (HRT) on efficiency of UAHR

The CPWW contained appreciable amounts of suspended, dissolved and total solids. The higher amount of suspended solids present in CPWW might be due to the presence of pectin, protein and sugars, which are biodegradable in nature. The concentrations of these organics vary with quantity of water used for processing of coffee berries (Shanmugapa *et al*., 1998).

The BOD of the CPWW ranged from 3,800 to 4,780 mg/L, which might be due to the presence of high amount of organic substances. The high level of COD concentration (6,420 to 8,480 mg/L) in the CPWW could be attributed to the slowly degrading compounds present in the CPWW. The CPWW contained considerable amounts of nitrogen (125.8 to 173.2 mg/L), phosphorus (4.4 to 6.8 mg/L) and potassium (20.4 to 45.8 mg/L), which might be due to the presence of pectin, protein and sugars in coffee berries.

Treatment of CPWW using UAHR

Startup process

The variation in different parameters of coffee processing wastewater during startup period was observed. Initial decrease in COD removal efficiency could be due to the absence of sufficient quantity of bacterial population, which is responsible for the anaerobic digestion of wastewater (Haandel and Lettinga, 1994). As the population is gradually developed in the reactor and the stabilization of the consortium takes place, the bioconversion rate is improved with enhanced substrate utilization. Hence the COD removal efficiency also increases and reaches a maximum of 70.58 %. Similar initial decrease in COD removal efficiency was reported by Mendoza and Rivera (1998) due to the sudden increase of organic loading rate in the treatment of CPWW using anaerobic hybrid reactor.

The BOD_5 removal efficiency was 33.3 % on the second day and increased to 71.87 % at the end of the startup period. Haandel and Lettinga (1994) reported decreasing and fluctuating trend of BOD_5 removal efficiency during the startup period in biomethanation of cheese manufacturing wastewater through UAHR, which is due to the absence of sufficient quantity of microbial population.

Achieving near neutral pH level in the treated effluent was the indication of healthy anaerobic environment and satisfactory methanogenic activity. The overall performance of the reactor during the startup was more satisfactory. It is known that the selection of seed material plays a crucial role in minimizing the time required for initial biofilm establishment (Salkinoja-Salonen *et al*., 1983). The pH of 6.61 was achieved in the treatment of dairy wastewater using UASB system by Mahadevaswamy *et al*. (2004). The reason might be the good buffering capacity in the reactor and higher microbial activity. The TS removal efficiency was increased to 64.61 % at the end of startup period. Hickey (1991) has reported that the change in pH from slight acidic to near neutral, facilitates the proper growth of the bacterial population which in turn results in the increased TS reduction.

The biogas production was increased from 0.045 L/d at initial to 1.350 L/d at the end of startup period. The reason for the increased biogas production is due to proper anaerobic population development and sequential conversion of metabolic products developed at different stages of anaerobic digestion. During startup period, the maximum total quantities of biogas production were 535.71, 489.13 and 281.25 L/kg of TS, BOD and COD removed, respectively. Similarly the biogas production of 556 L/kg of TS removal was achieved in the treatment of Cassava starch factory effluent using UAHR (Shaji and Kamaraj, 2003). The methane content was initially 28.0 % and increased to 60.2 % at the end of startup period, which is comparable to 52% to 63 %, reported during the treatment of sago wastewater in anaerobic filter by Khageshan and Govindan (1995). The methane content was fluctuated initially and steadily increased to 60.2 % at the end of startup period. Vavilin *et al*. (1996) reported that the fluctuation in methane content may be due to the slow growth of anaerobes especially methanogens in the reactor as the methanogens depends on the metabolites of other organism for their nutrient requirement.

Table 3: Effect of HRT and OLR on the efficiency of UAHR

HRT (h)	COD loading rate (kg/m^3/day)	COD removal (%)	BOD removal (%)	TS removal (%)	Biogas production (L/kg of COD reduction)	Biogas production (L/kg of BOD reduction)	Biogas production (L/kg of TS reduction)
24	7.01	70	71	64	280	490	535
18	9.55	61	66	58	430	775	840
12	14.23	52	59	49	390	620	690
6	28.41	46	54	42	264	400	440

Process optimization

During each change in HRT, an initial unstablity was noticed in the COD and BOD removal efficiency ; but stability was attained after few days for each HRT. The variation in COD of treated effluent during initial period of operation at HRT=18 h was due to sudden increasing of the initial OLR; it enhanced the biological oxidation upto a certain point and then started to inhibit the degradation rate, because in strong wastewater containing high organic load, significant amounts of fatty acids can develop from partial degradation of substrate and these can inhibit the methanogenic population in the reactor (Uyanik *et al.,* 2002). Similarly, the reduction in the reactor performance for a short period after increasing the organic loading was reported by Kumar *et al.* (2008) when treating industrial cluster wastewater. They noted that, an additional period was required to reach the steady sate again, when HRT was changed. Fig. 2 shows the removal of COD, BOD and TS as influenced by HRT and OLR. Among the different HRTs, at 24 h, the maximum efficiency in reduction of pollution load of BOD, COD and TS to a level of 66%, 61% and 58%, respectively. The pollutant load in terms of COD removal efficiency decreased from 70 to 61 per cent with corresponding HRT from 24 h to 18 h, due to increasing of OLR and reduction of HRT.

Fang and Chui (1993) reported that the COD removal efficiency of the UASB reactor was mainly dependent on the COD loading rate and HRT of the reactor operation. Not much work has been reported using hybrid reactors with wastewater from coffee processing. But in other studies using different wastewaters, such as high strength wastewaters like poultry slaughter house wastewater, hybrid reactor was effective and resulted in 80% and 86% of Total COD (TCOD) and Soluble (SCOD) removal efficiency, respectively was achieved (Rajakumar and Meenambal, 2008).

The total quantity of biogas produced was maximum at HRT=18h in the range of 840.0, 775.0 and 430.0 L/kg of TS, BOD and COD removed, respectively. Lettinga (1995) reported that the reduction of BOD and COD contributed to the gas production. Similarly, Diamantis *et al*. (2005) achieved a biogas production of 240 L/kg of COD removal in the biomethanation of fruit canning wastewater through hybrid reactor.

The maximum reactor efficiency was found at both 24h and 18h HRTs and 24 h performed higher activity than HRT=18 h. However, its magnitude varied with time. For instance, COD reduction was higher by 9%, BOD reduction by 5% and TS reduction by 5 % between 18h and 24h HRTs. The difference of reactor efficiency for the two HRTs was very little, but the time taken for pollutant reduction was minimum for HRT=18h comparing with HRT=24h; however aerobic treatment is necessary as a post treatment after anaerobic treatment to meet the Central Pollution Control Board (CPCB) standards for discharging of coffee processing wastewater into inland surface waters. The CPCB recommendation of COD level for discharging treated effluent into inland surface water is 250 kg/L. So the reactor is performed better in reduction of pollution load at HRT=18h within very short period of time.

The findings of this study showed that the UAHR is highly efficient in reducing the pollutant load and biomethanation of CPWW. The reactor performed better at HRT=18h with very short period of time. At 18 h retention time, reduction of COD, BOD and TS were 61%, 66% and 58%, respectively. This anaerobic treatment system, coupled with aerobic treatment with mechanical aeration as the post treatment, may be a suitable treatment system for the coffee processing wastewater as an eco-friendly approach, which requires further investigation.

ACKNOWLEDGEMENTS

The authors are thankful to the Coffee board, Govt. of India, for financing this research project on "Bioprocessing technologies for the value addition of coffee wastes".

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