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Treatment of Slaughterhouse Waste by an Anaerobic Hybrid Reactor

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Abstract: The study was carried out to assess the feasibility of using an anaerobic hybrid reactor for the treatment of slaughterhouse wastewater. The reactor, consisting of an Upflow Anaerobic Sludge Blanket (UASB) at the bottom and an anaerobic filter at the top, was seeded with the digested sewage sludge and was initially fed with neutralized acetic acid for the activation of methanogens. Subsequently slaughterhouse waste was fed to the reactor. The experiments were conducted in five different phases by varying the hydraulic retention time (HRT) from 24 hours to 18, 12, 8 and 4 hours. Influent chemical oxygen demand (COD) was increased from 760 mg/L to a maximum of 4200 mg/L. The organic loading was progressively increased from a low of 0.76 kg COD/m^3d^{-1} to a maximum of 20.24 kg COD/m^3d^{-1}. In the first phase of the study the organic loading rate (OLR) was increased from 0.76 kg COD/m^3d^{-1} to 2.88 kg COD/m^3d^{-1} and an HRT of 24 hours was maintained. The COD removal efficiency increased from 47.3% to 96% when the reactor achieved steady state conditions. For the next three phases the OLR was increased from 2.24 kg COD/m^3d^{-1} to 12.6 kg COD/m^3d^{-1} by decreasing the HRT to 18, 12 and 8 hours. The COD removal efficiency dropped for few days but regained within a short time and was around 95% for each loading rate. However, as OLR was increased to 20.24 kg COD/m^3d^{-1} and HRT was decreased to four hours, the COD removal efficiency decreased (64%). It is seen that the reactor performed well over a wide range of OLR and a COD and BOD removal efficiency of 95% was achieved till an HRT of eight hours. The solids removal efficiency was 73%. It is concluded that higher organic loadings can be applied to the reactor up to an HRT of eight hours and slaughterhouse waste can be successfully treated using anaerobic hybrid reactor. However additional units in series are required to bring the BOD level to permissible values.

Key words: Anaerobic, hybrid reactor, slaughterhouse waste.

Introduction

The slaughterhouse industry poses a significant environmental impact by discharging effluent to receiving waters containing high concentration of bio-degradable organic matter; thus contributing significant levels of biochemical oxygen demand (BOD) and other nutrients, resulting in riverbed and stream pollution, because slaughterhouse wastewaters have a complex composition and are very harmful to the environment (Polprasert et al., 1992). It contains high concentrations of biodegradable organics mostly from fats and proteins, sufficient alkalinity, and adequate phosphorous and micronutrients for microbial growth. It does not include toxic compounds and has a relatively warm temperature between 20 and 30°C (Massé et al., 2000). These wastes have a characteristic brownish, blood-like appearance and a repugnant odour. Of all the compounds of the abattoir effluent stream, blood constitutes the highest pollution load, followed by fats. Blood is also the single-most significant source of nitrogen in abattoir effluent. Aerobic treatment of slaughterhouse waste is not regarded as a suitable treatment option because of high-energy requirement for aeration, limitations in liquid phase

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oxygen transfer ratio and large quantities of sludge production (Torkian et al., 2003) Slaughterhouse waste is well suited for anaerobic treatment (Metzner et al., 1990). Anaerobic bacteria can survive in unfed conditions for periods of time, an important feature for smaller slaughterhouses that operate just a few days a week (Massé et. al., 2000). Metzner and Temper (1990) and Tritt (1992) used fixed bed reactors for the anaerobic digestion of slaughterhouse wastewaters and obtained greater than 90% COD removal efficiency. Borja et al. (1994), reported a 94% COD removal efficiency at an operating temperature of 35°C, an organic loading rate (OLR) of 10.1 kg $m^{-3}d^{-1}$ and a hydraulic retention time (HRT) of 12 hours. The suspended and colloidal components in the form of fats, proteins and cellulose can have an adverse impact on the performance of UASB reactors leading to the deterioration of microbial activity and washout of active biomass (Lettinga et al., 1997; Nunez et al., 1999). This may limit the operation of OLR of 4-6 kg $m^{-3}d^{-1}$ (Lettinga et al., 1991).

A higher OLR value of upto 45 kg $m^{-3}d^{-1}$ has been reported only for anaerobic hybrid reactors and a bentonite packing as a biomass support (Borja et al., 1995). Very limited information is available on the performance of anaerobic hybrid reactors under high OLR. Thus, the objective of the present study was to investigate the effect of loading rate on the performance of anaerobic hybrid reactors (consisting of a UASB and AF) for the treatment of slaughterhouse wastewater. The individual efficiencies of UASB and AF were also studied.

Materials and Methods

The experiments for the current study were conducted in a laboratory scale anaerobic hybrid reactor, consisting of a UASB at the bottom and an AF at the top. AF provided effective gas solid separation. The reactor was fabricated with Perspex material and had an internal diameter of 50 mm and a height of 111 cm as illustrated in Figure 1.

The porosity of the randomly packed filter media cutting from PVC used in this reactor was found to be 85% giving the effective volume of the reactor as 1.77 L. The height of the UASB reactor was 0.45 m and that of anaerobic filter was 0.53 m. A freeboard of 0.13 m was also provided. The media used for anaerobic filter was of PVC pipe, which has been cut, nearly into 25 mm diameter size with a rough surface to a length of 28 mm. The reactor volume of anaerobic filter was approximately 0.884 litres, which is the same as the volume of the UASB

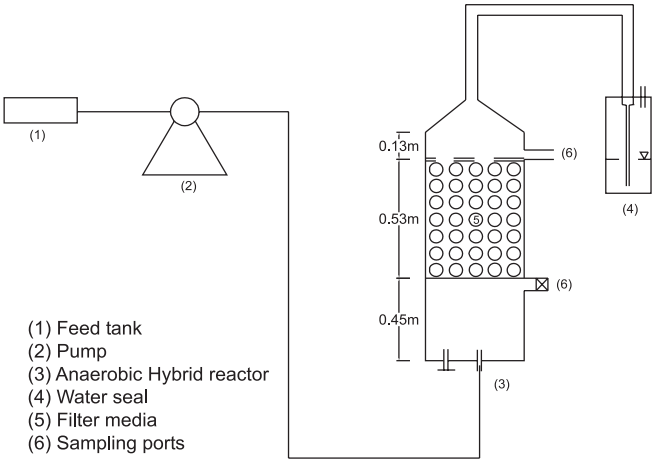

Figure 1: Experimental setup for the study.

in the bottom part. Volumes were kept the same so as to keep the HRT the same in both parts of the hybrid reactor. The temperature was maintained in the range of 30-35 °C and the pH of the feed solution was in the range of 7.2-7.5. In the start up phase of the study 40% of the reactor volume was inoculated with the seed anaerobic sludge obtained from the anaerobic digester of Okhla Sewage Treatment Plant, New Delhi. The seed sludge had a volatile suspended solids (VSS) content of 27.9 g/L.

The wastewater used for the study was obtained from a slaughterhouse situated at Aligarh. Table 1 shows the characteristics of wastewater.

Table 1: Characteristics of the wastewater under study

Parameters	*Values*
COD (mg/L)	5000
BOD_5 (mg/L)	3000
Alkalinity (mg/L as $CaCO_3$)	1500
pH	7.5
Total solids (mg/L)	5210
Dissolved solids (mg/L)	5098

Experimental Protocol

The experiments were conduced in five different phases by varying the HRT from 24 hours to 4 hours. Influent chemical oxygen demand (COD) was increased from a low 760 mg/L to a maximum of 4200 mg/L. OLR was progressively increased from a low 0.76 kgCOD/m^3d to a maximum of 20.24 kgCOD/m^3d.

In the first phase of the study, between days 16 and 58, the influent chemical oxygen demand (COD) was increased from 760 mg/L to 2880 mg/L with a progressive increase in the OLR from 0.76 kgCOD/m^3d to 2.88 kgCOD/m^3d. HRT was kept at 24 hrs during this phase.

In the second phase of the study (i.e. between days 58 and 66) the influent chemical oxygen demand (COD) was increased from 2060 mg/L to 3280 mg/L with a progressive increase in the OLR from 2.74 kgCOD/m^3d to 4.37 kgCOD/m^3d. The HRT was kept at 18 hrs during this period. The third phase of the study, from day 66 to day 71, observed an increment in the chemical oxygen demand (COD) from a value of 1620 mg/L to 3280 mg/L. The OLR was increased from a value of 3.24 kgCOD/m^3d to 6.56 kgCOD/m^3d. HRT was kept at 12 hrs during this phase. The fourth phase of the study ranging between day 71 and day 87 was provided with an increase in the chemical oxygen demand (COD) from a lower value of 2400 mg/L to a maximum of 4200 mg/L resulting in an increase in OLR value from a low 7.2 kgCOD/m^3d to a maximum of 12.6 kgCOD/m^3d. HRT was kept at 8 hrs during this second last phase. Finally for the last phase (between day 87 and day 92) of the study, the influent chemical oxygen demand (COD) was increased from a value of 3200 mg/L to 3360 mg/L. OLR was also given an increment from a value of 19.27 kgCOD/m^3d to a maximum of 20.24 kgCOD/m^3d for the last day of the experiment. HRT during this phase was kept at 4 hrs. The reactor was located in the temperature controlled room maintained at 30–35 ^oC.

Sampling and Analysis

Routine analyses including COD, BOD_5, pH, alkalinity, and solids (total and soluble) were performed using procedures outlined in the standard methods for the examination of water and wastewater (APHA, 1985). The pH, alkalinity and COD were monitored daily while BOD and solids were monitored once a week. A one to two week acclimatization period was usually allowed after any change in loading.

Results and Discussion

The present study deals with the assessment of the performance of an anaerobic hybrid reactor with varying organic loading rate for the treatment of slaughterhouse wastewater. Initially the reactor was fed neutralized acetic acid (1000 mg/L) and was operated at an HRT of 24 hours. This was continued for two and half weeks and 87% COD removal efficiency was achieved. During this period nutrients were added to the feed because acetate lacks the necessary nutrients required by microorganisms for their growth. Subsequently slaughterhouse waste was fed into the reactor and the loading was gradually increased by decreasing HRT and increasing COD concentration. Nutrient supplementation was stopped, as slaughterhouse wastewater possesses essential nutrients. The experiments were conducted in five different phases as explained in the earlier section. Influent COD concentration was increased from 760 mg/L to a maximum of 4200 mg/L and organic loading rate was varied from 0.76 kg COD $m^{-3}d^{-1}$ to 20.24 kg COD $m^{-3}d^{-1}$. The results of the experiments are summarized in Figure 2. Figure 2 shows the variation of influent and effluent BOD, COD and total solids with time. It is seen

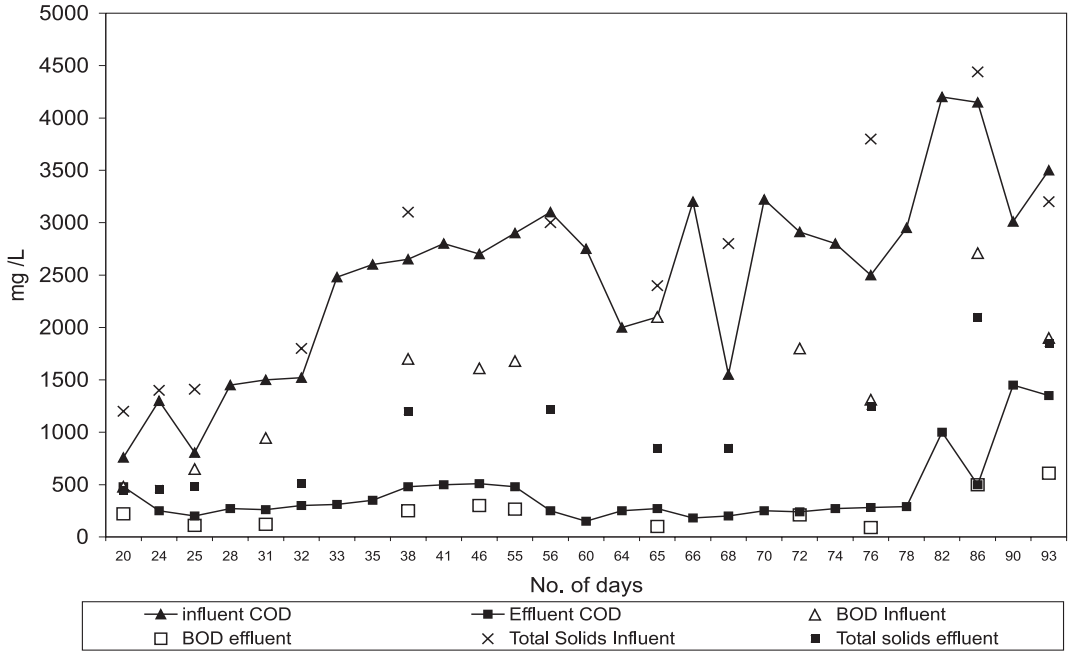

Figure 2: Variation of BOD, COD and Total Solids with time.

that the effluent COD remained constant in the initial phase. However, whenever there was an increase in the organic loading rate the effluent COD increased slightly but again decreased after few days. This may be due to a slight organic shock to the microorganisms. However, after few days of acclimatization the microorganisms were able to degrade the increased concentration of slaughterhouse waste.

It is seen that the COD removal efficiency remained above 80%, throughout most of the experiment. However, in the last phase of the study, OLR was increased to 20.24 kg/m^3d and the HRT was reduced to four hours. The COD removal efficiency drastically decreased to below 55%. It recovered to a value of 64% on the last day of experiment. Considering the fact that HRT at this phase was low at four hours, the decrease in performance could have also been attributed to insufficient time available for substrate transfer from the liquid to biomass, apart from a high organic loading rate of 20.24 kg COD/m^3d. Figure 2 also shows the variation of influent and effluent BOD with time. The trend is similar to that of COD. The effluent BOD remained more or less constant till an HRT of eight hours. However, as the HRT decreased to four hours, effluent BOD increased. Figure 2 also shows the variation of total solids with time. It is seen that only 73% of the total solids removal efficiency was achieved.

The influent pH of the feed solution was varied from 7.2 to 7.5. The effluent pH value was around 7.4. The influent alkalinity ranged from 1100 mg/L as $CaCO_3$ to 1480 mg/L as $CaCO_3$. Alkalinity increased from approximately 1200 mg/L as $CaCO_3$ to about 2490 mg/L as $CaCO_3$ in the effluent. The alkalinity of the effluent was sufficient enough to provide a buffer for the anaerobic hybrid reactor. The increase in alkalinity was mainly caused by the mineralization of protein into ammonia. The latter combines with the carbonic acid in solution to form an ammonium bicarbonate buffer.

Figure 3 shows the variation of organic loading rate with treatment efficiency. As explained earlier the treatment efficiency decreased at the maximum organic rate of 20.4 kg COD $m^{-3}d^{-1}$.

Conclusions

The results of the study show the feasibility of an anaerobic hybrid reactor for the biodegradation of slaughterhouse effluent. Based on the results, the following conclusions are drawn from this study:

- The COD and BOD of the waste were reduced by up to 95%;

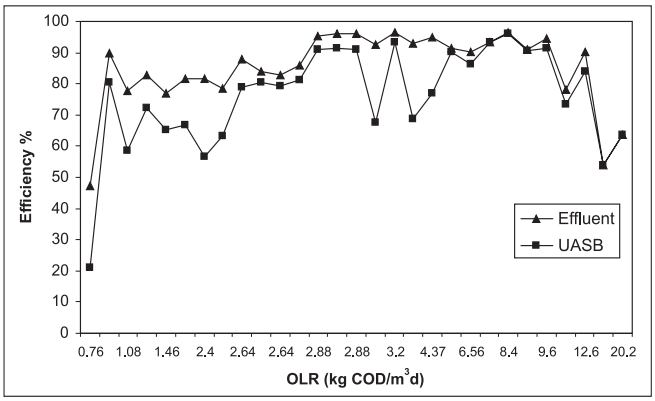

Figure 3: Variation of organic loading rate with treatment efficiency.

- The reactor performed well over a wide range of organic loading. Up to an organic loading of 12.6 kgCOD/m^3d the maximum treatment efficiency achieved was up to 95%;
- The HRT was varied during the experiment. The experiments were started from 24 hrs HRT and it was subsequently decreased to 18, 12, 8 and finally 4 hrs. Up to an HRT of 8 hrs the reactor performed well and treatment efficiency of up to 95% was achieved but reducing the HRT to four hours drastically reduced the efficiency of the reactor;
- Even after achieving up to 95% BOD removal efficiencies, the effluent BOD concentrations were higher than the disposal standards for streams. This accounts for further treatment or dilution of the waste.
- pH of the effluent was noted to be in the range of 7-8;
- Alkalinity of the effluent remained constant throughout the experiment; and
- The total solids and dissolved solids reduction was not as good as would be desired.

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