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Treatment of high strength wastewater by anaerobic hybrid membrane bioreactor (An-HMBR)

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Abstract

In this study high strength synthetic wastewater was treated in a 15.7-L Anaerobic Hybrid Membrane Bioreactor (An-HMBR). The Hydraulic Retention Time (HRT) for the reactor was 3 days whereas the Solids Retention Time (SRT) was kept 100 days. The Organic Loading Rate (OLR) in the reactor was maintained at 1.06 kg COD/m^{3}·d. The total COD removal efficiency was achieved higher than 98%, at operating conditions. The acclimatization and stabilization of reactor was achieved in around 2 months. At steady state condition a total reduction in COD of 98.5%, 99% and 99.5% occurred in suspended growth, attached growth, and membrane system respectively. During the entire operation, the membrane was required to be physically cleaned once after 30 days of operation. Hence Anaerobic Hybrid Membrane Bioreactor can be successfully used to treat high strength wastewater.

Keywords: Anaerobic Hybrid Membrane Bioreactor (An-HMBR), attached growth, waste-water, OLR, HRT, SRT.

Introduction

The global water demand has increased since the last century as well as the water consumption rate has also increased with increasing population. If the rate of consumption continues, the freshwater resources may get consumed in upcoming years[1]. To minimize the pressure on water resources, sustainable waste water treatment technologies have been developed recently. In this context, to treat various types of high strength waste water AnMBR has been widely applied all over the world. AnMBR has been recognized as a compact and very promising technology for treating high strength wastewater. It possesses several advantages over aerobic and conventional anaerobic waste water treatment system, such as high quality effluent, small footprint, systematic energy i.e. biogas production (without added cost of aeration)[2], low sludge generation, with high treatment efficiency[3-5].

In AnMBRs the membrane decouples the HRT from SRT and provides solid-liquid separation[6], which reduces sludge wasting and generates solid free effluent. The conventional anaerobic systems such as up flow Anaerobic Sludge Blanket (UASB) reactor and Expanded Granular Sludge Bed (EGSB) reactor configuration principally meet the requirements necessary for high-rate anaerobic treatment[7,8]. These reactors usually have a greater performance in terms of membrane fouling and biomass yield, but they are more complex and expensive in all aspects[9]. In present study a modified anaerobic hybrid membrane bioreactor has developed which combines anaerobic digestion, attached growth system and membrane system in single reactor. In attached growth system sponge has been used which acts as a growth media for microbial consortia. This hybrid system provides alternative strategies for high strength waste water treatment with potential of high effluent quality and energy generation.

The objective of the current study is to estimate the efficiency of this novel integrated suspended and attached growth anaerobic hybrid membrane bioreactor (An-HMBR) for treating high strength waste water. The performance of the system was evaluated based on COD removal efficiency and changes in sludge properties at mesophilic temperature (35°C).

Materials and methods

Experimental setup: Membrane bioreactor configuration: A lab scale Anaerobic Hybrid Membrane Bioreactor (An-HMBR) was constructed of Plexiglas having an effective working volume of 15.7 L. The bioreactor was having five sampling ports (P1, P2, P3, P4, P5) along the height of the reactor with one influent and one effluent port. The reactor was divided into three compartments. The lower compartment of the anaerobic reactor is the sludge bed (~ 50% of the total volume of reactor). The sludge composed of anaerobic microbial consortia which is responsible for methane generation by utilizing organic matters. The middle compartment (25% of reactor volume) served as attached growth or fixed growth system which is packed with polyurethane foam to reduce the sludge loss and load on the membrane. The attached biomass on the surface of the sponge forms a bio-film which provides greater surface area for wastewater contact which helps in improving the treatment efficiency[10]. This hybrid bioreactor is followed with a membrane chamber (25% of reactor volume) containing flat sheet microfiltration ceramic membrane module (Prova

Technotrade Pvt Ltd) with 0.1 micron pore size under submerged condition. The synthetic feed wastewater flow rate was maintained by peristaltic pump. The membrane-filtered effluent was extracted (30 min on/10 min off) with a vacuum pump connected to the membrane module. The top portion of the reactor consists of a dome shape compartment for collecting gas. The temperature was maintained at 35˚C. To maintain a suitable flux, the membrane module was cleaned either physical or chemical methods as per requirement. As the reactor was maintained at anaerobic condition it is covered with a black paper to avoid any phototrophic algal growth which in turn may generate O_2 which obstruct the internal condition of the reactor. The schematic diagram of An-HMBR illustrated in Figure-1.

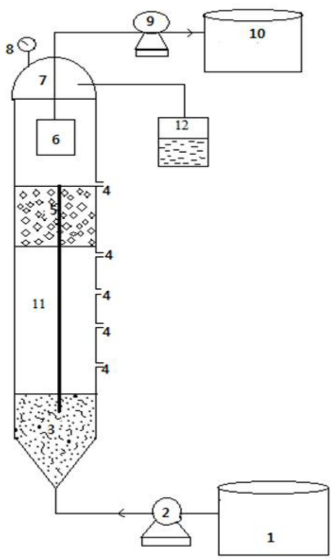


Figure-1: Schematic diagram of An-HMBR.
1. Feed tank, 2. Peristaltic pump, 3. Sludge bed, 4. Sampling ports (P1, P2, P3, P4, P5), 5. Attached growth media, 6. Membrane module, 7. Gas collection dome, 8. Pressure gauge, 9. Vacuum pump, 10. Effluent tank, 11. Heater, 12. Gas collection.

Attached growth system: Polyurethane sponge with density of 39 kg/m^3 was employed as the attached media in An-HMBR. The sponge cubes with size of 1 cm^3 were selected as previously optimized by Guo et al.[11]. The sponge cubes were placed in the second compartments of An-HMBR which is 25% of the total reactor volume.

Feed wastewater preparation and composition: The feed wastewater simulating high strength wastewater was prepared synthetically. The feed wastewater was comprised of a soluble and highly biodegradable substrate, along with essential macro- and micro-nutrients required for optimal growth of anaerobic microbial consortia. Synthetic feed with Chemical Oxygen Demand (COD) concentration was maintained at 3.2 g/L. The composition and concentration used in the synthetic feed was similar to that of cultivating anaerobic bacteria by Krishna et al[12]. The synthetic feed constituted dextrose as a carbon source. The detail of the feed composition is provided in Table-1. $NaHCO_3$ (2500 mg L^{-1}) was added to adjust pH (~7) and buffering capacity.

Table-1: Composition of synthetic feed[12].

Nutrients	Composition (g/l)
NH_4Cl	0.5
KH_2PO4	0.25
K_2HPO_4	0.25
$MgCl_2.6H_2O$	0.3
$NiSO_4$	0.016
$FeCl_3$	0.025
$CoCl_2$	0.025
$MnCl_2$	0.015
$CuCl_2$	0.0105
$CaCl_2$	0.005
$ZnCl_2$	0.0115
Glucose ($C_6H_{12}O_6$)	3
$NaHCO_3$	25

Characteristics of anaerobic seed sludge: The anaerobic sludge was collected from anaerobic digester from sewage treatment plant for seeding the reactor. Before seeding, the raw sludge was screened through a sieve, in order to eliminate the large sized debris and fibers. The characteristics of anaerobic sludge are summarized in Table-2.

Table-2: Characteristics of anaerobic sludge.

Parameters	Unit	Average
TSS	mg/l	8800
VSS	mg/l	4411
VSS/TSS	-	0.50
SVI	-	99.5

Experimental work: Analytical Procedures: The performance of the reactor was evaluated by monitoring COD removal throughout the reactor operational period. In addition, to assess the performance of the reactor methane gas generation along with pH, VFA, Alkalinity, ammonium nitrogen, Suspended

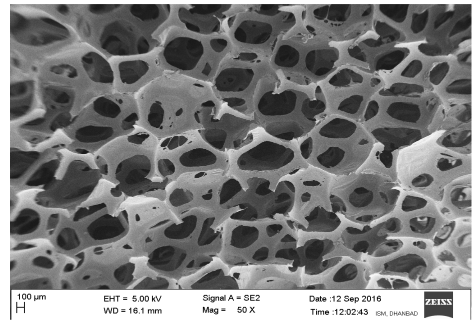
Solids (SS) Volatile Suspended Solids (VSS) were monitored and recorded. The analytical methods for monitoring the above mentioned physicochemical parameters were adopted as per the guideline outlined in American public health association[13]. Biogas production was also monitored using water displacement method which was based on the Mariotte principle.

Operating conditions: The An-HMBR was operated at Hydraulic Retention Time (HRT) of 3 days (72h). The Solid Retention Time (SRT) was maintained at 100 days at Organic Loading Rate (OLR) of 1.06 kg COD/m^3.d. Feed water was pumped in up-flow direction through bottom of the reactor using peristaltic pump and effluent was collected from effluent port using vacuum pump. Trans-Membrane-pressure (TMP) was maintained constantly at 600 mmHg. The inflow rate of feed wastewater was maintained at 3.95 ml/minute. The pH of the An-HMBR system was in the range of 6.8 to 7.9. To monitor fouling rate in the membrane, flux was used as an indicator and was monitored regularly. When the flux declined, membrane module was taken out of the reactor, and cleaned physically with tap water to remove the cake layer on the membrane surface.

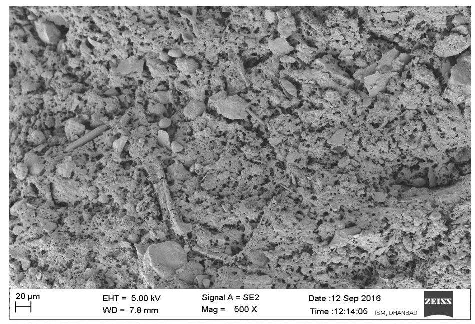
Results and discussion

Startup and stabilization: The startup period is considered as time required for stabilization of the reactor for stable operation. In this study the reactor was seeded with 2 L of inoculums and the temperature was maintained at 35˚C. Before start-up, the reactor was allowed to fill with synthetic feed waste water, and then left it for preliminary acclimation for 24 h. Influent pH was in the range of 6 to 8. Main operation parameters were used to be monitored every day, and others twice in a week, with samples from the different ports of the reactors and effluent along with gas production. A number of parameters were analyzed, in which the most important were Chemical Oxygen Demand (COD), alkalinity, Volatile Fatty Acids (VFA), biogas generation recorded daily and Total Solids Content (TSS), volatile suspended solid (VSS) were recorded weekly.

Study of Attached growth as bio-film on the sponge: In general, sponge retains two different form of biomass: one is on the surface and other is trapped inside the void space of the sponge[14]. During experimental period it was shown that excess biomass released from attached growth system was less as compared with suspended growth system. This could be due to biomass that is produced gets attached into the void space and surface of the sponge. Scanning Electron Microscope (SEM) images of sponge surface were taken before starting up Figure-1(a) and after completion of the experimental period Figure-1(b). In Figure-1(a) it is clearly showed that the sponge before utilization in the An-HMBR has large numbers of clear pore space. On the other hand, after completion of operation period, the pore spaces are completely covered with biomass on the surface of the sponge Figure-1(b). This demonstrates that the sponge can act as a perfect support for biomass development. It is an excellent media for active biomass as it provides an ideal mobile carrier to them[4,15].



(a) Before acclimatization



(b) After acclimatization

Figure-2: SEM image of sponge surface before and after acclimatization.

Membrane study: TMP and flux: The resistance of the membrane used in the An-HMBR was measured by flux quantification. The An-HMBR was started up with a HRT of 3 days and maintained throughout the operational period. During An-HMBR operation, TMP experienced a constant trend; constantly at 600 mmHg (79.98kPa), but the flux experienced fluctuation during whole operational period. In present study the membrane was cleaned once in 30 days of operation when flux declined to < 25 Lm^{-2}/h (LMH). After cleaning, the flux gradually increased to 30 Lm^{-2}/h (LMH) (Figure-2). At the end of the operation (60 d), the flux again declined to 20 Lm^{-2}/h (LMH). To maintained acceptable flux, physical or chemical cleaning technique may applied to control fouling issues of membrane submerged in the reactor.

An-HMBR treatment performance: Table-3 presents the percentage (%) of COD removal efficiency during entire operational period with different sampling ports at mesophilic temperature under anaerobic conditions. The results showed that the efficiency of different ports varied slightly among them in the reactor during the first 20 days. Moreover, the outcomes indicate that the efficiency of different ports were found in ascending order (P1<P2<P3<P4<P5<E) in terms of COD removal. The results also indicated that the final effluent from the membrane system achieved highest COD removal i.e. over 90% but other ports also showed minor variations.

This higher efficiency of the reactor is due to the simultaneous action of anaerobic microbes, sponge and membrane system. As microbes degrade >80% COD while sponge acted as attached media on the surface for anaerobic consortia that enhanced biodegradation. The maximum COD removal efficiencies were achieved at 60 days of operation.

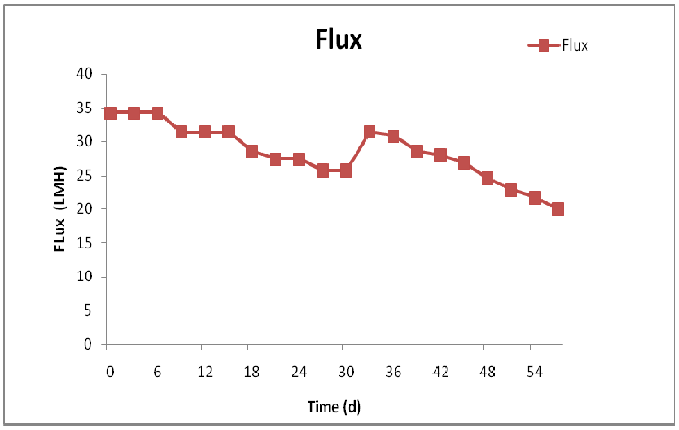


Figure-3: Variation of flux in An-HMBR.

Table-3: % of COD removal efficiency from different ports in anaerobic conditions.

Days	COD removal efficiency (%)					
	P1	P2	P3	P4	P5	E
20	70	85	88	90	91	92
40	90	91	94	95	97	98
60	97	98	98	99	99	99

It was observed from Figure-3 that the final COD concentrations in submerged, attached and effluent form membrane filtrate were found to be 60 mg/l, 48 mg/l, and 32 mg/l respectively. The removal efficiencies gradually enhance during whole operation period. The COD removal efficiency of 91 ± 10% was observed in Suspended, 92 ± 9% in attached system and 93 ± 9% in effluent at OLR of 1.06kg COD/m^3.d. This result indicates that An-HMBR is able to achieve high COD removal efficiency, in treating high strength waste water.

Table-4: Efficiency of An-HMBR for COD removal at steady state conditions.

Parameters	P1	P2	P3	P4	P5	E
pH	7.4± 0.95	7.4± 0.9	7.6± 1	7.9± 1.1	7.9± 1.1	8± 1
COD (%removal)	95± 20	96± 02	97± 01	98± 01	99± 01	99± 01
TSS (mg/L)	196± 4	169± 7	120± 6	105± 9	91± 10	63± 12

The concentration of COD in the effluent during initial days of the reactor was in the range of 30-35% (based on total COD Influent and total COD Effluent). After one month of operation, COD removal gradually increased, showed COD removal efficiency higher than 80% (Figure-4). During initial days (first 30 d) of the operation, the reactor attained the removal efficiency of 80 ± 2% (Mean ± Standard deviation) for total COD in the reactor. The steady state COD removal efficiency increased from 98±01 to 99±01 and pH range from 7.9±1.1 to 8±1 for submerged and final effluent respectively (Table-4). These outcomes of the experiment are comparable with conventional anaerobic MBRs, with COD removal efficiency ranges from 75% to 99%[16]. In addition, Ma et al.[17] in his experiment for treatment of real municipal waste water reported that, the efficiency of COD removal was 79%. Results revealed that anaerobic system along with attached growth and membrane filters can consistently achieve high treatment efficiency with lower capital cost and in small footprint. Similarly, in this study, the reactor was started with a low concentration of biomass (0.9 g/L VSS), the complete rejection of the microorganisms in the reactor by the membrane along with sponge increased gradually (4 g/L VSS) within 2 month of operation. This could be due to the full rejection of microbes by sponge and membrane. The membrane in this reactor also exhibited some fouling issue during operation period. The fouling in An-HMBR influenced different operational conditions such as waste water composition, sludge characteristics, membrane characteristics.

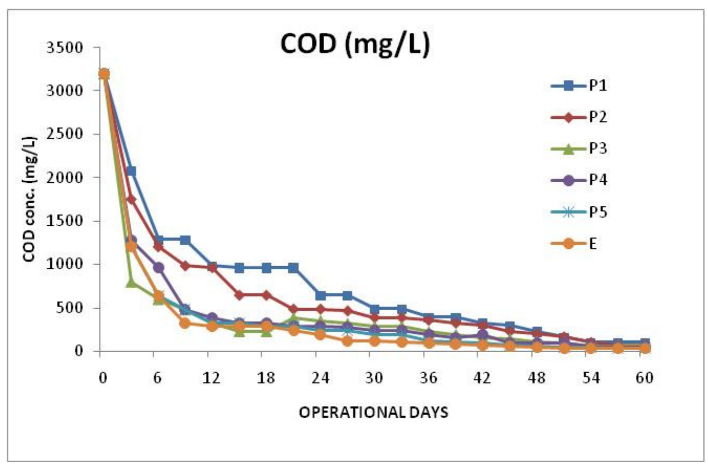


Figure-4: Concentration of COD removal from different ports.

Biogas production: The most important aspect of anaerobic treatment of waste water is the biogas generation, acts as a potential energy source. However, biogas production was influenced by COD loading rate. In anaerobic digestion the anaerobic bacteria converts the carbon content of the wastewater into biogas[18]. In this study, production of biogas was monitored during the operation of An-HMBR. During the initial days of study, biogas production was low (<150 ml/d). This low production of biogas may be due to non acclimated anaerobic seed sludge or were un-adapted previously[19, 20]. The 2 months of continuous operation enhances the rate of production of biogas (~100-500 ml/d). The increase of biogas production could be due to the acclimation of the anaerobic consortia to mesophilic temperatures.

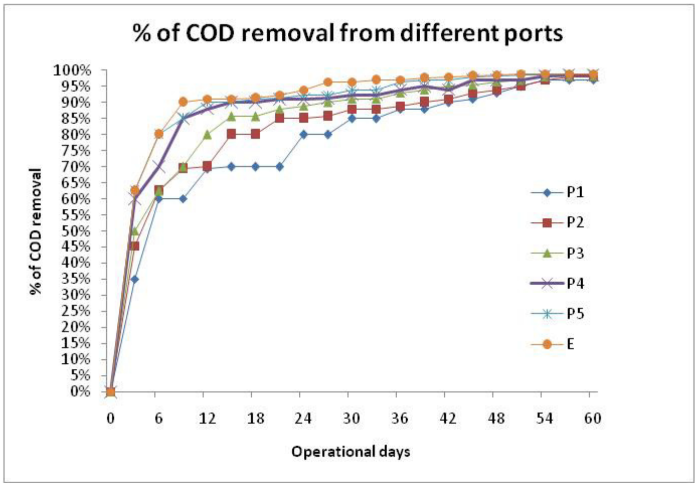


Figure-5: % of COD removal from different ports.

Conclusion

The study evaluated the combination of three different treatment systems suspended, attached and membrane filters. In this study, the An-HMBR showed high COD removal efficiency (> 95%) at pH 7 at mesophilic temperature (35˚C). Biogas production increased with stabilization of the reactor (500 ml/day of biogas at 1.06kg COD/m^3.d of loading rate).The study concluded that the An-HMBR is technically feasible for treatment of high strength waste-water with respect of COD removal and biogas production. In this study, 3 days HRT was used although it is greatly depends upon the OLR and substrate concentration in the reactor. Sponge acted as ideal attached growth system and helps to reduce cake layer formation thus reduction in membrane fouling. Hence it may be concluded from present study that the high strength wastewater can be successfully treated using the An-HMBR reactor and the effluent may be reused in agricultural/irrigation purposes.

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