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PERFORMANCE EVALUATION OF LEACHATE TREATMENT USING LAB SCALE MOVING BED BIO FILM REACTOR (MBBR)

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Abstract: The Moving bed biofilm reactor (MBBR) system is the promising technology for the effective nutrient and organic removal from leachate in terms of achieving high nutrient removal efficiency by reducing the operating cost. Moving bed biofilm reactor (MBBR) technology has become popular in the field of leachate treatment because of its many advantages such as high capacity, high efficiency, relatively small footprints compared with the conventional treatment systems. MBBR is a continuous flow process where higher concentration of active biomass can be maintained for biological treatment without increasing the reactor size. The system is mainly based on the aeration and special designed carriers to provide a surface colonized by bacteria. For the growth of the microorganisms on the PE carriers, the MBBR system should be operated at favourable operating conditions by maintaining suitable carrier filling rate, aeration rate and HRT for the removal of DOC and NH_4-N. At 20% filling rate the carriers moved uniformly and helped prevent the accumulation of excess biomass on the surface of the carriers as well as loss of biomass due to collision of the carries. Experimental results show that that the aeration rate of 4.5 L/min was favourable for the growth of active and effective microorganisms in PE carriers and gave higher nutrient and organic removal from leachate. The biomass concentration on the carriers increased with 2hr HRT. From experiments, it was demonstrated that the optimum operating condition for the effective nutrient and organic removal efficiency at 12 L volume of the reactor were; 20% of PE carrier filling rate by the volume of reactor, 4.5 L/min aeration rate and HRT of 2 h. The DOC removal efficiency at 20% PE carriers filling rate was found the highest and uniform (88.2%). The NH_4-N removal was effective at 20% filling rate.

Keywords: Leachate, MBBR, HRT, Aeration rate, Carrier filling rate, DOC, NH_4-N.

1. Introduction

With urbanization, population growth and industrialization, the amount of municipal solid waste has increased sharply, and landfill is the most common way to dispose solid waste, but this has also led to the production of a large amount of landfill leachate. Municipal Landfill leachates contain high concentrations of organic content (values of COD vary from 100 to 70900 mg/L), high amounts of ammonia (ranging from 0.2 to 13000 mg/L) and refractory organic materials (Renoua et al., 2008). MBBR process is based on the use of suspended porous polymeric carriers, kept in continuous movement in the aeration tank, while the active biomass grows as a biofilm on their surfaces. Researchers have proven that MBBR systems possess advantages such as high biomass concentration in the bioreactor, high organic loading rates, great tolerance to loading shocks, relatively less reactor size and no sludge bulking problem (Chen et al., 2008). Moving bed biofilm reactor (MBBR) technology has become popular in the field of leachate treatment because of its many advantages such as high capacity, high efficiency, relatively small footprints compared with the conventional treatment systems. MBBR is a continuous flow process where higher concentration of active biomass can be maintained for biological treatment without increasing the reactor size. The system is mainly based on the aeration and special designed carriers to provide a surface colonized by bacteria (Rahimi et al., 2011).

Chu et al. (2011) investigated the performance of MBBR for the removal of organics and nitrogen from leachate with a low C/N ratio using the two different materials as a carrier for their research, namely PUF and biodegradable polymer PCL particles. This study demonstrated the MBBR with PUF had good results in the TOC and ammonium removal, 90% and 65%, compared with 72% and 56% for reactor filled with PCL carriers at an average HRT of 14 h. This is because of the higher attached microorganism on the PUF enhanced the nitrifiers to reside. The MBBR with biodegradable PCL carrier showed good performance in terms of TN removal (59% with PCL carriers and 14% with PU carriers) as these carriers are an effective substrate providing reduced power for denitrification.

Nutrient and organic constituents in leachates are consumed by microorganisms that lives within the leachates in the process of their growth. These microorganisms, when got suitable surface to attach, grow more rapidly in the presence of favourable condition and perform effectively in leachate treatment process. The suitable surface may be the wood, sand, mud or plastic materials and the favourable condition for these microbial growths depend on the factors like percentage of carrier filling rate, aeration rate, HRT etc.

Many researches have been carried out using MBBR but there is no specific research on this particular carrier such as the effect of carrier filling rate, aeration rate and HRT in nutrient and organic removal from leachates. Therefore, this project aims to carry out series of lab scale experimental investigation on the effects of the carrier filling ratio, aeration rate and HRT on the performance of MBBR and optimize the operation conditions in a cost-effective way and evaluate optimum operating conditions for MBBR system in terms of carrier filling rate, aeration rate and HRT.

2. Materials and Methods

2.1 Materials

2.1.1. Study area details

Erode city is the headquarters of Erode District, TamilNadu, India which sprawls over 120 km^2 and lies between11° 17' N and 11° 23' N latitudes and 77° 40' E and 77° 46'E longitudes (Fig-01). The average altitude of the region is about 172 m above the mean sea level. It is situated at the center of the South Indian Peninsula, about 400 kilo-metres southwest from the state capital Chennai and on the banks of the rivers Cauvery and Bhavani. It is located on the western bank of the Cauvery River, while its twin city, Pallipalayam, is on the eastern bank of the river. Erode in general is characterized with scanty rainfall and a dry climate.

Erode has moderate-dry weather throughout except during the monsoon seasons. It also experiences heavy rains primarily during the periods of monsoon with an average annual rainfall of 700 mm. The depth of ground-water table in Erode city varies from 1 to 15 m with respect to ground level. Erode city, with a population of over 1,50,000 is estimated to generate about 75 tonnes of garbage daily. The daily per capita generation of solid waste in Erode city ranges from 100 g to 500 g, which depends upon the economic status of the community involved (Mor et al). The important categories of MSW in the city includes waste from household, industries and medical establishments. The solid waste generation rate also varies from 0.66 kg/capita /day to 0.44 kg/capita/day in rural areas (Ogwueleka). The earliest landfill was started in Erode in 1963 near Vendipalayam at a distance of 1 km from the city centre. Three landfill sites within the city premises are filled and closed. All of them are unlined and nonengineered landfill sites. At present three functioning landfill sites are located at Vendipalayam, Semur and Vairapalayam.

The characteristics of the leachate samples collected from the Vendipalayam landfill sites are presented in Table 1.

Table 1 Leachate characteristics at Vendipalayam landfill site

Parameters	Concentration at Vendipalayam landfill site
pH	6.9
TDS	25514 mg/L
BOD	17,552 mg/L
COD	25,102 mg/L
Ammonium Nitrogen	1932 mg/L
NO_3^-	361 mg/L

2.1.2 Polyethylene (PE) carriers

The PE carriers, circular in shape with the diameter of 4.50 cm were used as biofilm carriers. These carriers consist of smaller dividers inside the carriers and fins outside where microorganisms can attach and grow on. The characteristics of PE carriers used in this experiment are summarized in Table 2. The picture of PE carriers is shown in Figure 1. These PE carriers were slightly lighter than the density of water (1 g/cm^3) and developed specifically for use in leachate treatment reactors.

Table 2. The characteristics of PE carriers

The specific surface area	6.22 cm^2
density	0.613 g/cm^3
weight of each PE carriers	1.226 g
Shape	Circular
Diameter	4.5 cm

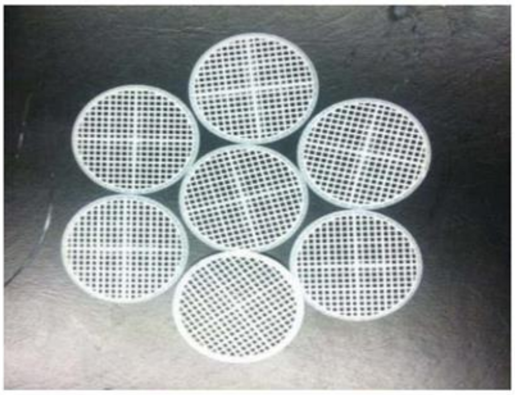


Figure 1 Polyethylene (PE) carriers

2.2 Methodology

2.2.1 Experimental conditions

Firstly, this study put forward a systematic study on the effects of PE carriers filling rate, aeration rate and HRT on nutrient removal in a continuous MBBR system. In order to achieve these tasks, an acrylic reactor with a working volume of 12 L was used. A sketch of the laboratory scale experimental setup is shown in figure 2.and the project activities shown in figure3.

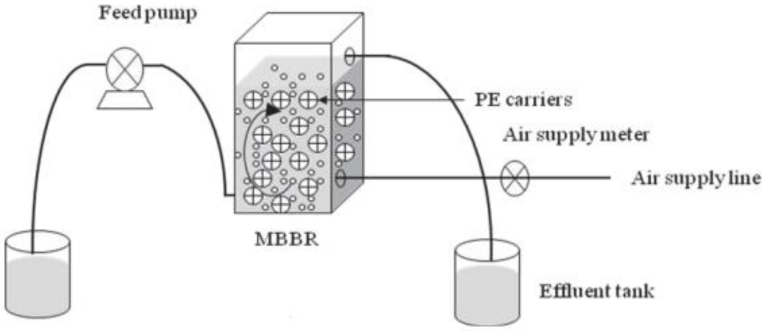


Figure 2 Experimental arrangements of MBBR

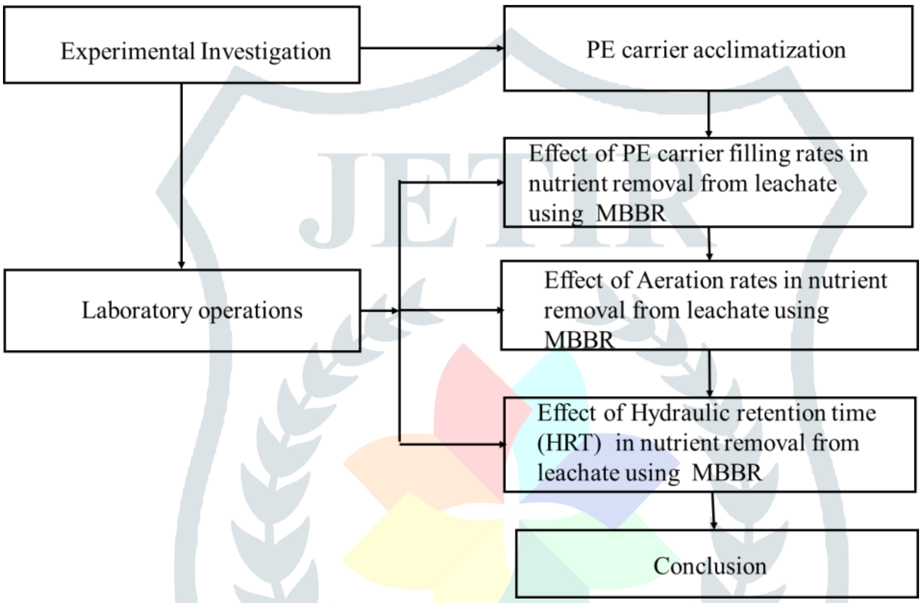


Figure 3 Flow chart of the project activities

The acclimatization of PE carriers is one of the essential components to provide preferably active biomass growth on the carriers so that this biomass can perform well in the wastewater treatment process. Therefore, about one month prior to starting experiment in the reactor, the PE carriers were acclimatized in a separate aeration tank (30 L) filled with synthetic wastewater and activated sludge from a wastewater treatment plant. Figure 4 shows the aeration tank used for the PE carriers acclimatization in the laboratory. Every day, 10 L synthetic wastewater was added in the aeration tank and pH was maintained to 7 by adding sulphuric acid (H_2SO_4) or sodium carbonate anhydrous ($NaHCO_3$) to support the microbial growth. MLSS in the tank was maintained to 8 - 10 g/L. The PE carriers were acclimatized after 25 days. The acclimatization of these PE carriers was determined by observing the biomass growth rate on the surface of PE carriers at every 5 days interval.

Figure 4 PE carriers acclimatization tank

For the first set of experiment, the acclimatized PE carriers were transferred into the reactor filled with synthetic wastewater. The filling volume of the PE carriers was started from 10% and increased to 20%, 30% and 40% by volume of the reactor respectively. The reactor was operated at least 20 days for each filling condition. The reactor was positioned with certain inclination (10º) giving some support at the bottom in order to create a uniform movement of PE carriers. The air was moving in the reactor by supplying the air through air diffuser at the bottom of the reactor. Air bubbles also supplied oxygen for the biological activity of biomass and kept the PE carriers floating and moving throughout the reactor volume accurately. The pH of the reactor was maintained to 7 everyday by adding H_2SO_4 or $NaHCO_3$. The DO of the reactor was observed 3.0 - 4.8 mg/L in all the cases. The synthetic wastewater was supplied from the bottom of the reactor using a feeding pump. Everyday 11.52 L synthetic wastewater was treated by the reactor with the constant aeration rate of 4.5 L/min and HRT of 25 h. In order to promote microbial growth on the carriers, the HRT was kept higher as the carriers were very sensitive and took long time for acclimatization. However, once the microorganisms grow on the carriers, they performed well in nutrient removal from the leachate. MLSS concentration in the reactor was in the range of 0.19 – 0.32 g/L at all the cycles. Every day the influent and effluent sample was taken and stored in fridge by adding adequate acid. The biomass growth rate in PE carriers and oxygen uptake rate (OUR) of suspended and attached biomass in the reactor were measured at every 5 days interval.

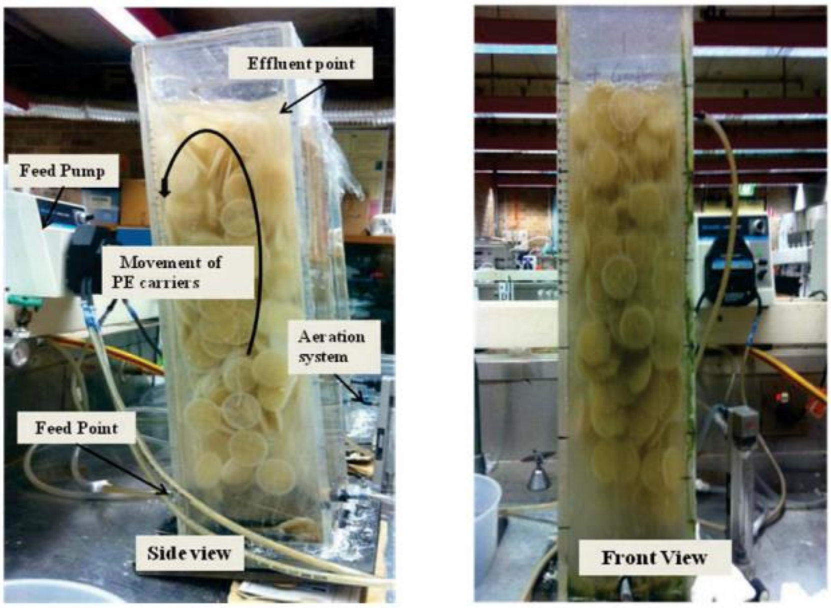


Figure 5 Laboratory setup of MBBR

2.2.2 Analytical methods

The analysis of COD and the measuring of MLSS were carried out according to Standard Methods (APHA, 1998). The COD was measured using COD reagent and a photometry. The MLSS and MLVSS was measured by filtering the mixed liquor sample through a GFC Whatman's 1.2 μm filter paper. The retained solid residue on the filter paper was dried by placing in an oven at 105 ºC for 2 h followed by desiccation for 20 min and finally weighted to calculate the MLSS. Then the dried residue on the filter paper was again heated in a furnace at 550 ºC for 20 min followed by desiccation for 20 min and weighted to calculate MLVSS. The oxygen consumption measurement can be achieved through the use of oxygen electrode with oxygen permeable Teflon membrane. The voltage generated from the reaction is proportional to the oxygen concentration of the sample and produces oxygen uptake during a period of 2 – 30 min. pH and DO of the reactor were measured everyday using pH meter and DO meter respectively.

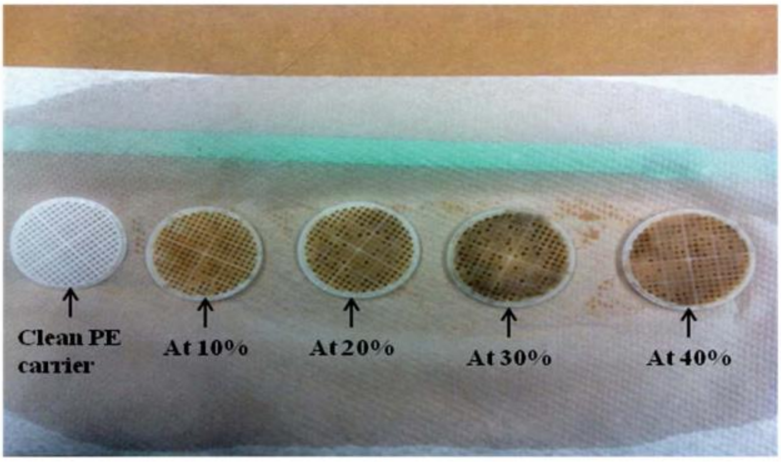
2.2.3 Biomass growth rate calculation

To determine attached biomass fixed in PE carriers, three pieces of the PE carriers were taken out of the reactor and kept in three separate beakers with millique water. The beakers were inserted into Ultrasonic cleaner until the attached biomass on the carriers were slugged off from the carriers. Then the solution of biomass and milique water was filtered through a GFC Whatman's 1.2 μm filter paper. The filter paper was then kept in the oven at 105 ºC at least for 1 h followed by desiccation for 20 min and measured weight. The filter paper was again kept in a furnace at 550 ºC for 20 min followed by desiccation for 20 min and measured weight. The average biomass was calculated as the average MLVSS value of the acclimatized carriers.

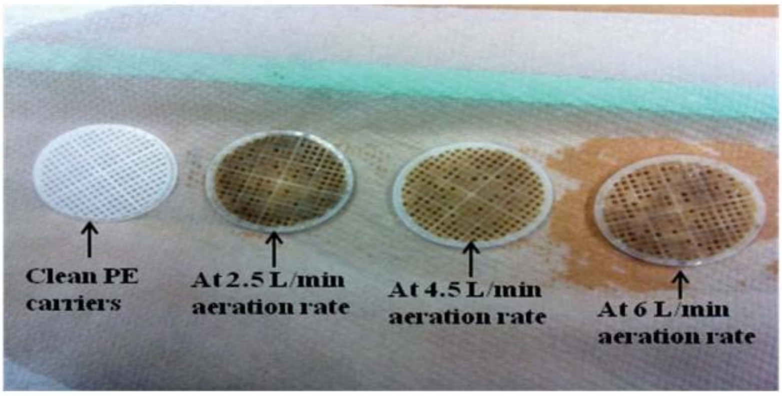
3. RESULTS AND DISCUSSIONS

3.1.1 Evaluation of microbial growth in PE carriers and its performance at different carriers filling rates, aeration rates and HRTs

For the growth of the microorganisms on the PE carriers, the MBBR system should be operated at favorable operating conditions by maintaining suitable carrier filling rate, aeration rate and HRT. The attached biofilm layer in PE carrier at different filling rates and aeration rates are shown in Figure 6 (A) and (B) respectively. At 20% carrier filling rate the average biomass growth rate was 15.7 mg/g while the growth rate were 10.6, 22.4 and 24.4 mg/g at 10, 30 and 40% carrier filling rates, respectively. At 20% filling rate the carriers moved uniformly and helped prevent the accumulation of excess biomass on the surface of the carriers as well as loss of biomass due to collision of the carries. Thus, the biomass in the carriers could consume the more organics and nutrients in the presence of adequate DO level and their removals were the highest compared with the 10, 30 and 40% filling rates.



(A)



(B)

Figure 6 Biomass growth in PE carriers at different (A) filling rates and (B) aeration rates)

According to the experimental results, it was concluded that the aeration rate of 4.5 L/min was favourable for the growth of active and effective microorganisms in PE carriers and gave higher nutrient and organic removal from leachate. The biomass concentration on the carriers increased with decreasing HRT of MBBR. The results showed that when the HRT was decreased from 25 h to 2 h, the biomass concentration on PE carriers was increased from 15.7 to 21 mg/g and the carriers were fully covered with the biofilm. This increased biomass concentration on the carriers enhanced the organic and nutrient removal from the system.

3.1.2 DOC removal efficiency

As oxygen plays an important role in nitrogen and phosphorus removal, DO consumed by the biomass should be monitored. The results exhibited that the higher the DO consumption rate, the more efficient of the bacterial biodegradation could be achieved. Guo et al. (2007) also demonstrated this type of results in their experiment. All these parameters indicated that the removal efficiency achieved by the system was mainly due to the attached growth biomass on the PE carriers.

The DOC removal efficiency was found above 85% at all filling rates and the average removal efficiency at 20% PE carriers filling rate was found the highest and uniform (88.2%). Although the removal efficiency at 30% filling rate was observed higher sometimes (around 90.6%), the overall performance was very fluctuating owing to the no uniform movement of the carriers in the reactor that obstructed the carrier fluidization. These results also showed that the MBBR system achieved higher DOC removal efficiency at 20% PE carrier filling rate under the same condition of influent organic loading rate.

The trends of DOC removal rates at different operating conditions are displayed in Table 3, 4 and 5 and Figure 7, 8, and 9 respectively.

Table 3 Average DOC removal rate variation of the biomass on the leachate at different PE carrier filling rates.

PE carrier filling rate (%)	Time (days)	DO Concentration (%)
10	0	100
	2	82.8
	4	82.5
	6	82
	8	81.3
	10	81
	12	80.4
	14	79.2
	16	77.8

	18	76.4
	20	75.6
	22	73.8
	24	72
	26	72.6
	28	73.4
	30	74
20	0	100
	2	88.2
	4	88
	6	87.7
	8	87.5
	10	87.3
	12	87
	14	86.8
	16	86.6
	18	86.3
	20	86.1
	22	85.9
	24	85.7
	26	85.4
	28	85.2
	30	85
30	0	100
	2	90.6
	4	90.3
	6	90.1
	8	89.9
	10	89.6
	12	89.5
	14	89.3
	16	89.1
	18	88.8
	20	88.5
	22	88.1
	24	87.7
	26	87.4
	28	87
	30	86.5
40	0	100
	2	92.6
	4	92
	6	91.9
	8	91.7
	10	91.5
	12	91.4

	14	89.9
	16	89.5
	18	88.9
	20	88.2
	22	87.9
	24	88.4
	26	89
	28	89.6
	30	90.2

Table 4 Average DOC removal rate variation of the biomass on the leachate at different Aeration rate

Aeration Rate l/min	Time (days)	DO Concentration (%)
2.5	0	100
	2	98.6
	4	94.8
	6	94.2
	8	92
	10	91.8
	12	91.6
	14	91.5
	16	91.4
	18	91.3
	20	91.1
	22	91.4
	24	91.5
	26	91.6
	28	91.8
	30	92.2
4.5	0	100
	2	92.4
	4	90.6
	6	88.8
	8	88.4
	10	87.6
	12	87.2
	14	86.5
	16	86.6
	18	86.3
	20	86.1
	22	85.9
	24	85.2
	26	84.7
	28	83.4
	30	82.5

6	0	100
	2	93.6
	4	93.3
	6	92.8
	8	92.5
	10	92.2
	12	92
	14	91.6
	16	90.3
	18	89.8
	20	89.5
	22	89.2
	24	88.7
	26	88.4
	28	88
	30	87.5

Table 5 Average DOC removal rate variation of the biomass on the leachate at different HRT

HRT (h)	Time (days)	DO Concentration (%)
2	0	100
	2	84.2
	4	80.6
	6	79.8
	8	79.2
	10	78.5
	12	78
	14	77.6
	16	77.2
	18	76.5
	20	75.3
	22	74.7
	24	74.6
	26	73.4
	28	71.8
	30	70.6
5	0	100
	2	86.4
	4	82.8
	6	81.7
	8	81.3
	10	81
	12	80.6
	14	80.2
	16	79.7
	18	79.2
	20	78.8

	22	78.4
	24	77.8
	26	77.2
	28	76.9
	30	76.5
8	0	100
	2	85.8
	4	85.3
	6	84.8
	8	84.2
	10	83.9
	12	83.4
	14	82.9
	16	82.5
	18	82
	20	81.6
	22	81.3
	24	81
	26	80.8
	28	80.4
	30	80
12	0	100
	2	95.2
	4	95
	6	94.6
	8	94.2
	10	93.9
	12	93.5
	14	93.2
	16	92.9
	18	92.5
	20	92.2
	22	91.8
	24	91.5
	26	91.2
	28	90.8
	30	90.4
25	0	100
	2	93.6
	4	92.8
	6	92.3
	8	91.5
	10	91
	12	90.6
	14	90.2
	16	89.5

	18	89.1
	20	88.3
	22	87.6
	24	87.1
	26	86.7
	28	86.2
	30	85.5

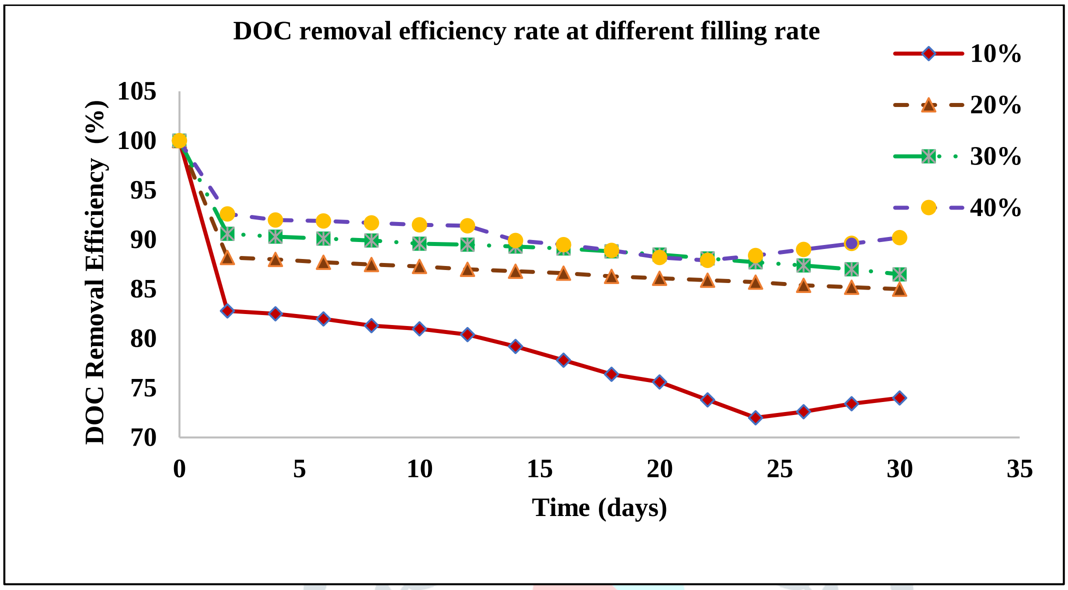


Figure 7 shows the DO consumption rates at different filling carrier rate

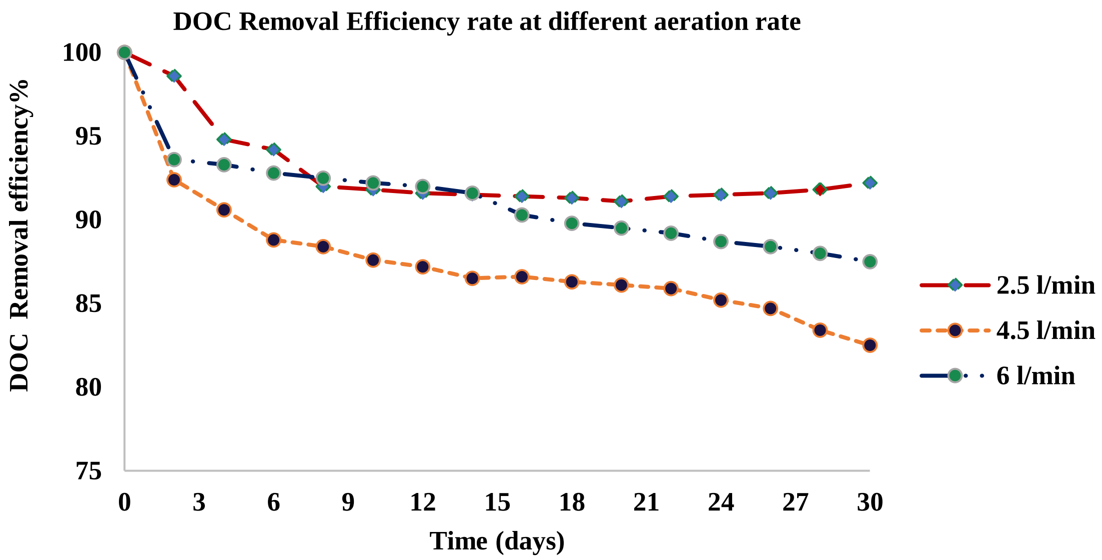


Figure 8 shows the DO consumption rates at different aeration rate

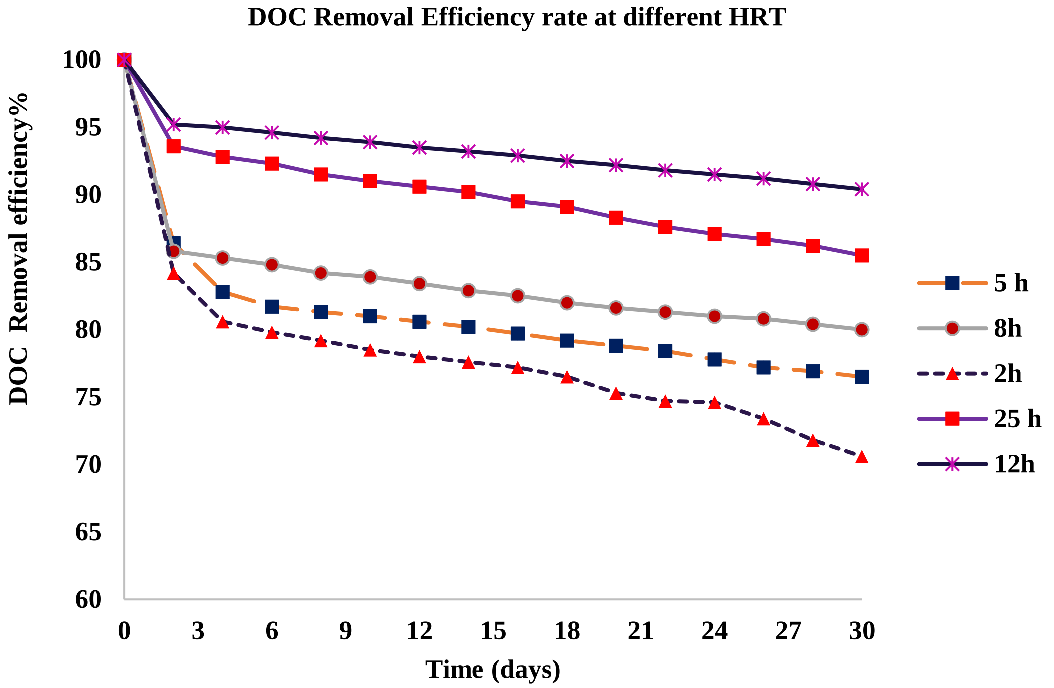


Figure 9 shows the DO consumption rates at different HRT

3.1.3 Ammonium Nitrogen removal efficiency on MBBR at different PE carrier filling rates

Aeration plays a vital role on the microbial growth and development, as well as its stability on the carriers and its movement throughout the reactor. Aeration supplies the microbial oxidation with oxygen and also enhances the turbulent intensity of fluid, which are important for the efficiency of wastewater treatment (Li et al., 2011).

Figure 10 shows the NH_4-N removal trend at different PE carriers filling rates. The NH_4-N removal achieved at 10, 20, 30 and 40% filling rate in MBBR showed that the NH_4-N removal was effective at 20% filling rate. In this experiment, from the day first to the day 15, NH_4-N removal efficiency fluctuated around 60% at all the filling rates. As the nitrification process was not good during that period because the microorganisms attached to the biofilm carriers required time to acclimate into the new environment. After day 16 at 20% carrier filling rate, the NH4-N removal efficiency increased to 75% and became constant while it was still fluctuating at 10, 30 and 40% carrier filling rates. As the carriers moved freely and uniformly throughout the reactor at 20% carrier filling rate, the nitrifiers got favourable condition to grow more inside the biofilm and got enough oxygen for the nitrification. Therefore, from the experimental results, the 20% carrier filling rate was considered as an effective filling volume for nutrient removal.

Table 6,7 and 8 describes the ammonium nitrogen removal at different filling rate, aeration rates and HRT respectively. Figure 10, 11 and 12 describes the ammonium nitrogen removal at different filling rate, aeration rates and HRT respectively for a period of 19 days.

Table 6 Ammonium Nitrogen removal Efficiency at different PE carrier filling rate

PE Carrier filling Rate	Time (Days)	Ammonium Nitrogen Removal Efficiency %
10	1	10.8
	3	45.6
	5	70.2
	7	56.5
	9	50.4
	11	45.8
	13	40.4

	15	33.6
	17	45.4
	19	28.2
20	1	55.9
	3	66.4
	5	48.2
	7	70.2
	9	78.4
	11	80.6
	13	45
	15	34.9
	17	78.2
	19	84.4
30	1	70.4
	3	65.6
	5	62.6
	7	72.4
	9	54
	11	58.2
	13	68.6
	15	54.8
	17	28.6
	19	78.2
40	1	82.6
	3	74.6
	5	73.8
	7	78.4
	9	55.6
	11	62.4
	13	68.8
	15	60.5
	17	67.9
	19	76.3

Table 7 Ammonium Nitrogen removal Efficiency at different Aeration rates

Aeration Rate (l/min)	Time (Days)	Ammonium Nitrogen Removal Efficiency %
2.5	1	70.3
	3	71.8
	5	74.6
	7	76.5
	9	75.2
	11	75
	13	74.8
	15	73.3
	17	73

	19	72.9
4.5	1	55.6
	3	58.4
	5	61.8
	7	63.2
	9	64.4
	11	65.8
	13	67.1
	15	68.5
	17	69.6
	19	70.4
6	1	35.6
	3	72.4
	5	74.2
	7	72.8
	9	65.2
	11	68.4
	13	69.2
	15	70.8
	17	67.6
	19	70.2

Table 8 Ammonium Nitrogen removal Efficiency at different HRT

HRT (h)	Time (Days)	Ammonium Nitrogen Removal Efficiency %
2	1	74
	3	68.2
	5	68.8
	7	64.5
	9	71.8
	11	59.5
	13	72.4
	15	75.6
	17	78.8
	19	76.7
5	1	72.4
	3	66
	5	74.5
	7	76.2
	9	68.7
	11	56.4
	13	72.2
	15	74.5

	17	80.2
	19	76.6
8	1	80.2
	3	78.4
	5	56.2
	7	58.8
	9	68.2
	11	70.4
	13	52.2
	15	54.8
	17	70.6
	19	72.2
12	1	64.6
	3	52.5
	5	58.6
	7	66.4
	9	72.5
	11	68.8
	13	68.2
	15	56.5
	17	67.9
	19	60.3
25	1	55.2
	3	52.6
	5	64.8
	7	68.5
	9	70.8
	11	58.5
	13	71.4
	15	74.6
	17	80.8
	19	81.6

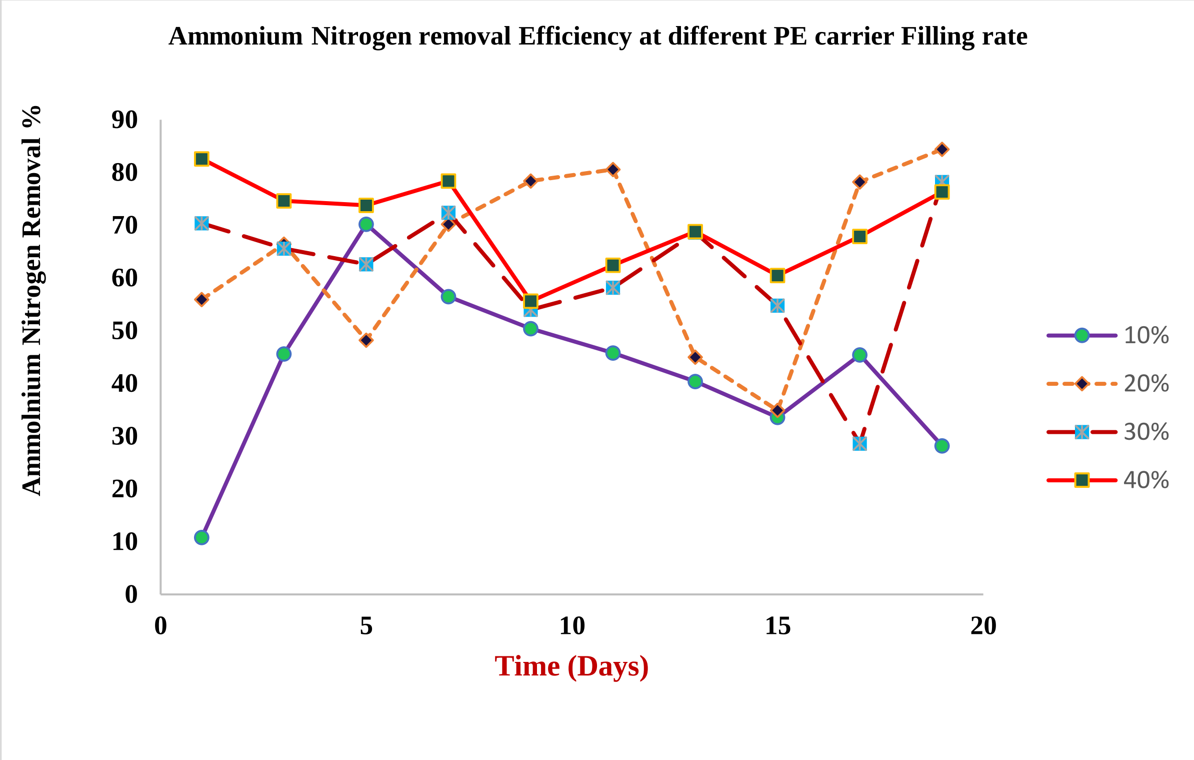


Figure 10 Ammonium nitrogen removal at different filling rate

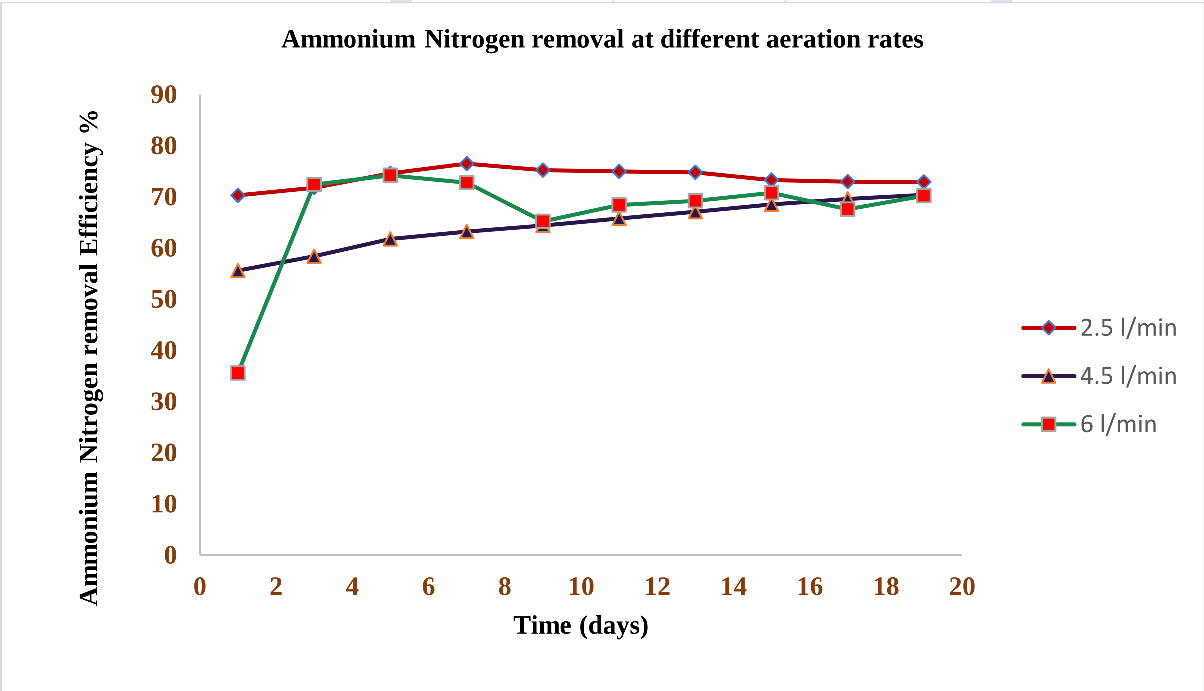


Figure 11 Ammonium nitrogen removal at different aeration rates

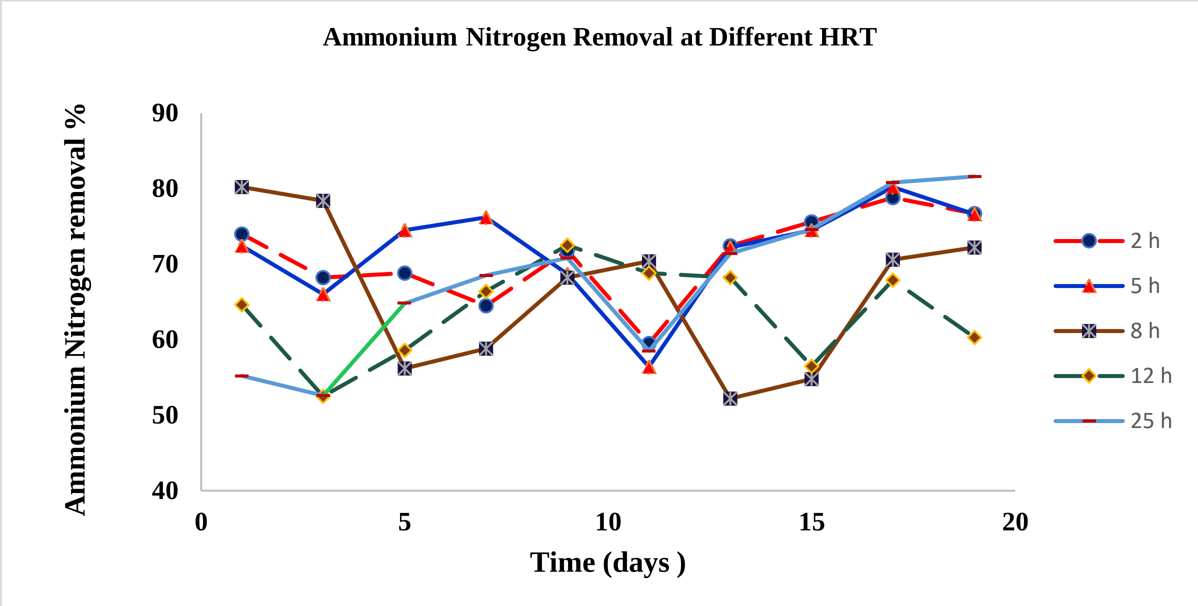


Figure 12 Ammonium nitrogen removal at different HRT

4 Conclusions

MBBR is gaining impetus around the world. Its application in leachate treatment is also growing. It is a leading-edge lea hate treatment technology as this system can operate at smaller footprints and give higher removal efficiency. Therefore, this project mainly focused on determination of optimum operating conditions for MBBR to enhance higher nutrient and organic removal efficiency.

From this experimental study, it was demonstrated that the optimum operating condition for the effective nutrient and organic removal efficiency at 12 L volume of the reactor were; 20% of PE carrier filling rate by the volume of reactor, 4.5 L/min aeration rate and HRT of 2 h. At that condition, the attached biomass developed on and inside the carriers can adsorbed enough foods (nutrient and organic matters) and DO from the wastewater and at the same time prevented the loss of the biomass from the carriers enhancing growth of thin layer of biomass in the carriers and improved the nutrient and organic removal efficiency. The supplied aeration produced the high kinetic energy and the PE carriers moved uniformly inside the reactor. It was also demonstrated in this experiment that the DOC removal was not significantly affected by the different operating conditions.

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