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COD AND SUSPENDED SOLID REMOVAL BY ANAEROBIC BAFFLED REACTOR: A case study of domestic wastewater from Van Lang University, Ho Chi Minh, Vietnam

Dieu, T. T. M, Phuoc. H. V

Department of Environmental Technology and Management, Van Lang University,
Ho Chi Minh City, 70000, Vietnam

Abstract

Experiments were carried out using 3 anaerobic baffle reactors (ABR) that have the same size. The reactors were made of glass with thickness of 5 mm, divided into five compartments. The first compartment has double volume compared to the remaining compartments. Dimension of the first compartment is 15 cm x 10 cm x 38 cm (width x length x height - inner face of tank), while the second compartment to the fifth compartment sized 15 cm x 5 cm x 38 cm. The study was divided into 2 periods. In the period 1, hydraulic retention time of the reactors were controlled in the range of 3-5 hours (ABR 1 – HRT 3h, ABR 2 – HRT 4h, ABR 3 – HRT 5h). In the period 2, the reactors of period 1 were continued operating with hydraulic retention time in the range of 1-3 hours (ABR 1' - HRT 1h, ABR 2' – HRT 2h, ABR 3' - HRT 3h). Sludge concentration maintained in the range of 2,888-3,172 mg/L. Domestic wastewater was taken at catch holes of the Van Lang University which had suspended solids (SS) concentration in the range of 80-290 mg/L and total COD of 176-352 mg/L. After the operation has obtained positive results, effectively remove organic material in domestic wastewater achieve 72-74% with effluent COD reached 64-80 mg/L, SS removal efficiency achieved 89-99% corresponding to SS output of 2-25 mg/L and the optimal HRT 4-5 hours.

When increasing organic loading rater (OLR) by reducing the hydraulic retention time in all reactors by 2 hours (ABR 1' - 1h with OLR from 4.61 to 8.06 kg COD/m^3.d, ABR 2' - 2h with OLR from 2.30 to 4.03 kg COD/m^3.d, ABR 3' – 3h with OLR from 1.54 to 2.69 kg COD/m^3.d), sludge concentration remains 2,968-3,172 mg VSS/L, after 15 days of operation, effectively removing organic matter best achieve 71-76% with COD decreased from 336 mg/L to 80-96 mg/L with HRT of 3 h.

Key words: *ABR, Anaerobic baffled reactor, domestic wastewater treatment.*

1. INTRODUCTION

Developed by McCarty and co-workers at Standford University, the anaerobic baffled reactor (ABR) was described as a series of upflow anaerobic sludge blanket reactors (UASBs) because it is divided into several compartments (Barber and Stuckey, 1999; Manariotis and Grigoropoulus, 2002). The ABR can be compared to a modified septic tank divided in compartments by vertical hanging and standing baffles. The baffles bring an advantage of limiting biomass washout as solids cannot bypass from the first compartment to last compartment (Polprasert et al., 1992; Barber and Stuckey, 1999; Bwapwa, 2010). Hydrolysis of particulate organics reactors may improve as they are retained in ABR for sufficient solid retention time. The ABR design helps to maximize the contact between the biomass and dissolved and suspended substances by forcing wastewater to flow under and over the baffles from one compartment to the next in succession (Dama et al., 2002). This is achieved both by maximizing the hydraulic retention time and solid retention time within the constraints of space and capital cost (Foxon et al., 2004 and Bwapwa, 2010). Advantages associated with construction of ABR include simple design, no moving parts, no mechanical mixing, inexpensive to construct, high void volume, reduce clogging, reduce sludge bed expansion, low capital and operation cost (Barber and Stuckey, 1999). Regarding to biomass, ABR also shows several advantages as no requirement for biomass with unusual settling properties, low sludge generation, high solid retention time, retention of biomass without fixed media or solid settling chamber, no special gas or sludge separation required.

For operation, ABR associates with low hydraulic retention time, intermittent operation, extremely stable to hydraulic shock loads, protection from toxic materials in influent, long operation times without sludge wasting, high stability to organic shocks (Nguyen et al, 2010). The versatility and the ability of the ABR in removing organic material, as demonstrated in laboratory-scale projects, suggested its application in the treatment of various types of wastewater including domestic wastewater. The main objective of this study is to evaluate organic matter and suspended solid removal efficiency of ABR treating domestic wastewater from Van Lang University, Ho Chi Minh City, Vietnam.

2. MATERIALS AND METHODS

2.1 Lab-scale ABR

The lab-scale ABR was designed to have working volume of 19 L and dimensions of 16 cm x 41 cm x 39 cm (width x length x height) with water height of 35 cm allowing a headspace of 4 cm. The reactor body and baffles were

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made of glass with thickness of 5 mm. The reactor consists of 5 compartments connected in series as presented in Fig. 1. The first compartment has dimensions of 15 cm x 10 cm x 39 cm while the other compartments have dimensions of 15 cm x 5 cm x 39 cm. Standing baffles have dimensions of 15 cm x 34 cm, are lower than the water height of 1 cm and the reactor height of 4 cm. Hanging baffles have dimensions of 15,0 cm x 34.5 cm, are above the reactor bottom of 2 cm, higher than water height of 1.5 cm and lower than the reactor height of 1.5 cm. Distance between the standing and hanging baffle is 1,5 cm. Gas release/collection valves and sampling valves were installed for each compartment. Inlet pipe with governor valve was installed above the reactor bottom of 1 cm and the outlet pipe lowered than the reactor height of 3 cm. These pipes have diameter of 5 mm. Each compartment has two valves: the upper one for sampling or removing supernatants and the bottom one for wasting sludge or releasing the mixture of each.

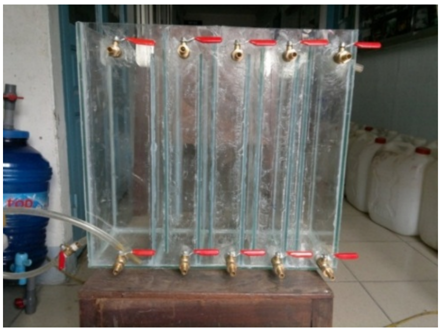

Fig 1 Layout of ABR

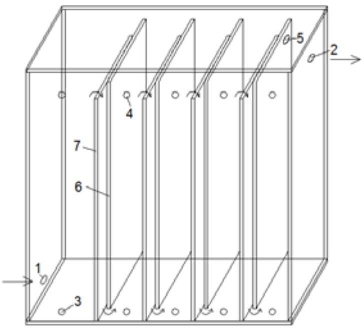

Fig 2 Lab-scale ABR: 1: Inlet; 2: Outlet; 3: Bottom valve; 4: Sampling valve; 5: Gas release valve; 6: Hanging baffle; 7: Standing baffle

Fig 3 Lab-scale ABR and completed mixed anaerobic reactor before operating.

Fig. 4 Lab-scale ABRand completed mixed anaerobic reactor in operation.

2.2 Operational parameters of period 1

Domestic wastewater from collection pit of Van Lang University with total COD in the range of 176-336 mg/L and SS in the range of 80-390 mg/L was used as feed to the reactors. Three ABRs namely ABR 1, ABR 2 and ABR 3 were operated in concourrent with different start up hydraulic retention times and organic loading rates. Experimental set-up of ABRs for the first period is summarized in Table 1.

Table 1 Experimental set-up for operting lab-scale ABRs during the first period

Parameters	ABR 1	ABR 2	ABR 3
Working volume (L)	19	19	19
Hydraulic retention time (h)	3	4	5
pH	7.0-7.5	7.0-7.5	7.0-7.5
Total COD (mg/L)	Original raw wastewater (COD ~ 176-336 mg/L, in average of 233 mg/L)		
SS (mg/L)	Original raw wastewater (SS ~ 80-290mg/L, in average of 177 mg/L)		
Organic loading rate ($kgCOD/m^3$.day)	1.41-2.69	1.06-2.02	0.84-1.61
VSS of each compartment (mg/L)	2,710-3,300		
VSS of ABR in average (mg/L)	2,888-3,040		

Three other completed mixed anaerobic bioreactors namely CMABR 1, CMABR 2 and CMABR 3 were desinged without baffles inside and having the same dimension of ABR. The CMABRs were operated with the same conditions as applied for ABRs to compared treatment efficiency of these types of anaerobic bioreactor for organic and suspended material removal. The mixture in the CMABRs was mixed thorougly by small fishpond pumps for circulating wastewater within the reactors. Effluents from these CMABRs went to secondary settling tanks before entering the storage tanks. Experimental set-up of CMABRs for the first period is summarized in Table 2.

Table 2 Experimental set-up for operting lab-scale CMABRs during the first period

Parameters	CMABR 1	CMABR 2	CMABR 3
Working volume (L)	19	19	19
Hydraulic retention time (h)	3	4	5
pH	7.0-7.5	7.0-7.5	7.0-7.5
Total COD (mg/L)	Original raw wastewater		

Parameters	CMABR 1	CMABR 2	CMABR 3
	(COD ~ 176-336 mg/L, in average of 233 mg/L)		
SS (mg/L)	Original raw wastewater (SS ~ 80-290mg/L, in average of 177 mg/L)		
Organic loading rate ($kgCOD/m^3.day$)	1.41-2.69	1.06-2.02	0.84-1.61
VSS of CMABR in average (mg/L)	2,923		

Experimental procedure were conducted as follows:

- Measure pH, COD, SS of wastewater;
- Weighing suitable amount of septic sludge for each compartment of the ABRs as well as each CMABR
- Adjusting pH of influent to 7.0-7.5 if it was higher than 8.5.
- Filling up the reactors with wastewater, mixing and taking sample to measure initial concentration of biomass in the reactors in terms of VSS;
- Controlling influent flowate by adjusting the governor valves;
- Effluents from ABRs were sampled and analyzed pH, COD, SS;
- Effluents of CMABR were taken from secondary settling tank with hydraulic retention time of 60 mins for analyzing pH, COD, SS;
- These reactors were operated until reaching steady state.

2.3 Operational parameters of period 2

The period 2 was conducted by increasing organic loading rates of the reactors of the period 1. As domestic wastewater from Van Lang University has low strength, organic loading rates were increased by decreasing hydraulic retention time (HRT). Thus, the ABR 1 of the period 1 was continued operating with HRT of 1 h (and namely ABR 1’). Similarly, the ABR 2 of the period 1 was continued operating with HRT of 2 h (and namely ABR 2’) and the ABR 3 became ABR 3’ with HRT of 3 h. By doing so, organic loading rates of these ABRs were reached 4.61-8.06 kg $COD/m^3.d$ (ABR 1’); 2.30-4.03 kg $COD/m^3.d$ (ABR 2’) and 1.54-2.69 kg $COD/m^3.d$ (ABR 3’). Experimental set-up of the ABRs for the second period is summarized in Table 3.

Table 3 Experimental set-up for operting lab-scale ABRs during the second period

Parameters	ABR 1	ABR 2	ABR 3
Working volume (L)	19	19	19
Hydraulic retention time (h)	1	2	3
pH	7.0-7.5	7.0-7.5	7.0-7.5
Total COD (mg/L)	Original raw wastewater (COD ~ 176-336 mg/L, in average of 233 mg/L)		
SS (mg/L)	Original raw wastewater (SS ~ 80-290mg/L, in average of 177 mg/L)		
Organic loading rate ($kgCOD/m^3.day$)	4.61-8.06	2.30-4.03	1.54-2.69
VSS of each compartment (mg/L)	2,910-3,450		
VSS of ABR in average (mg/L)	2,968		

Three CMABRs of the period 1 were also increased organic loading rates by reducing HRT in coresponding to those of ABRs. CMABR 1, CMABR 2, CMABR 3 of the period 1 were continued opertating in the period 2 with HRT of 1, 2 and 3 h, respectively and namely CMABR 1’, CMABR 2’ and CMABR 3’. Experimental set-up of the CMABRs for the second period is summarized in Table 4.

Table 4 Experimental set-up for operting lab-scale CMABRs during the second period

Parameters	CMABR 1’	CMABR 2’	CMABR 3’
Working volume (L)	19	19	19
Hydraulic retention time (h)	1	2	3
pH	7.0-7.5	7.0-7.5	7.0-7.5
Total COD (mg/L)	Original raw wastewater (COD ~ 176-336 mg/L, in average of 233 mg/L)		
SS (mg/L)	Original raw wastewater (SS ~ 80-290mg/L, in average of 177 mg/L)		
Organic loading rate ($kgCOD/m^3.day$)	4.61-8.06	2.30-4.03	1.54-2.69
VSS of CMABR in average (mg/L)	2,903		

2.4 Sludge

Septic sludge from Hoa Binh Fertilize Company was used to provide microorganisms in the bioreactors. Raw septic sludge was sieved to remove contaminants. Seed sludge has moisture content of 80% and VSS of 64% (by dry weight).

2.5 Wastewater

Wastewater used was taken from the collection pit of Van Lang University, located in District 1, Ho Chi Minh City, Vietnam for this study. Composition of the wastewater is described in Table 5.

Table 5 Composition of domestic wastewater from Van Lang University

Parameters	Unit	Value	
		Range	Typical
pH	-	6.83 – 8.08	7.60
Alkalinity	mg $CaC)_3/L$	110 – 300	213
SS	mg/L	80 – 290	177
COD	mg/L	176 – 336	233
sCOD	mg/L	112 – 267	169
$N\text{-}NH_4^+$	mg/L	64 – 86	79
$N\text{-}NO_3^-$	mg/L	0.05 – 2.00	0.81

3. Results and discussions

3.1 Period 1

The experiments were conducted for 17 days. It was found that ABRs reached steady state from day 9 of operation onwards. Total COD was reduced from 176 – 251 mg/L in the influent to 64-80mg/L in the effluent (Fig. 5). Compared to ABRs, CMABRs reached steady state from day 13 onwards and the remaing COD in the effluents after settling was in the range of 80-128 mg/L. Though organic loading rate of ABR 1 was higher than that of ABR 2 and ABR 3, but it seemed unsignificant different in

COD of the effluents. Within this period, organic loading rates of ABR 1, ABR 2 and ABR 3 at steady state reached 1.41-2.69 kg COD/m^3.d, 1.06-2.02 kg COD/m^3.d and 0.84-1.61 kg COD/m^3.d, respectively. Compared to experimental results found by Foxon et al. (2006, 2008) and Nast et al. (2008), hydraulic retention time of this study is shorter at the same organic loading rate. Foxon et al. (2006, 2008) operated ABR to treat domestic wastewater at organic loading rate of 0.4-0.7 kg COD/m^3.d with HRT of 22-42 h, while in the study of Nast et al. (2008), organic loading rate was controlled in the range of 0.67-2.10 kg COD/m^3.d with HRT of 8-24 h. However, it is also important to note that total COD of domestic wastewater used in the studies of these authors was higher, ranged from 680-716 mg/L (Foxon et al., 2006, 2008) and 505-914 mg/L (Nast et al., 2008) and COD of the effluents reached 105-225 mg/L. Higher removal efficiency of ABRs compared to that of CMABRs is attributed to plug flow mode of ABRs. pH of influents ranged from 6.87 to 7.99 and pH of the effluents reached 6.93-8.20 which suited for anaerobic microorganism growth without pH adjustment needed.

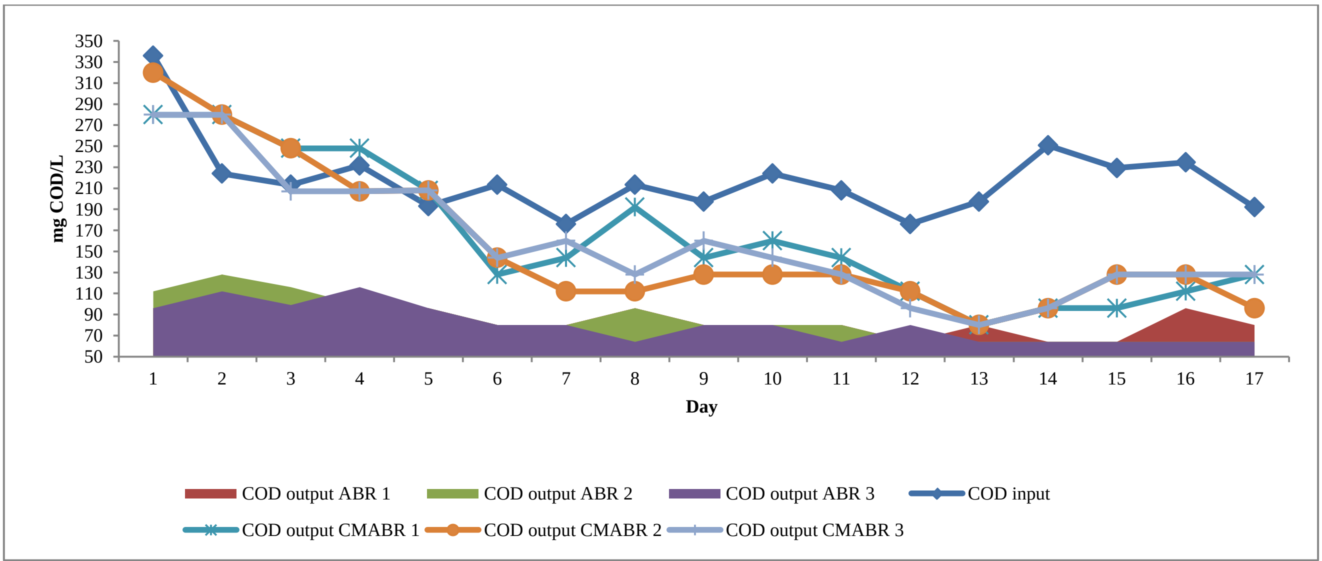

Fig 5 Changes of total COD of the influents and effluents of ABRs and CMABRs in the period 1.

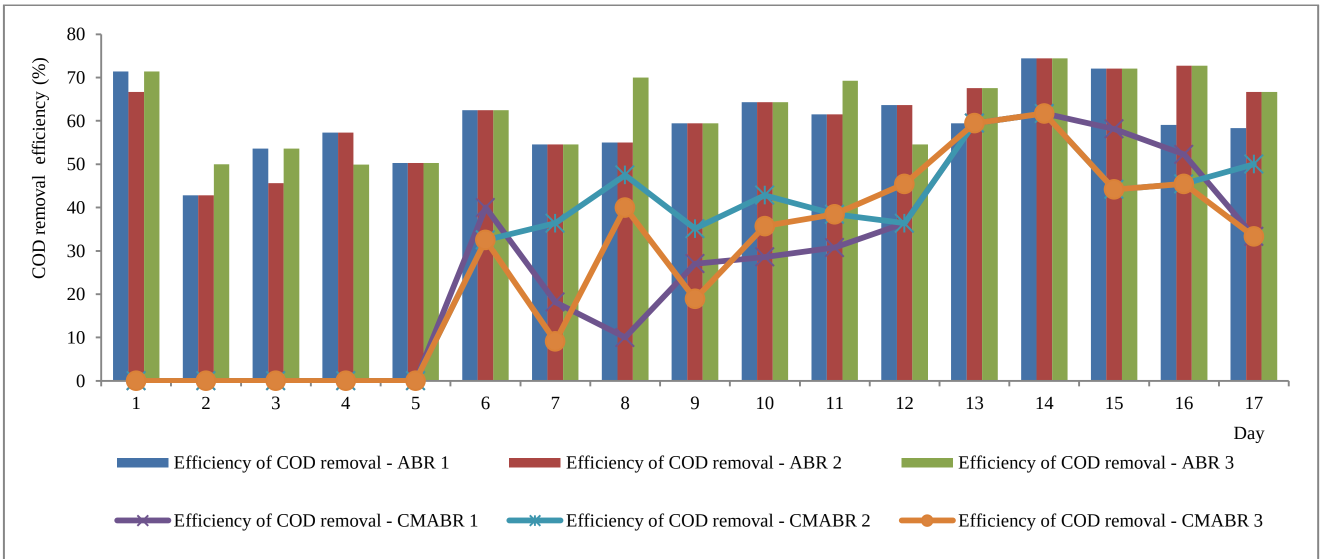

Fig. 6 Total COD removal efficiency of ABRs and CMABRs.

From day 8, suspended solid (SS) removal of ABRs reached higher than 90%, conressponding to SS reduced from 117-190 mg/L in the influent to 2-26 mg/L in the effluent. At the steady state, effluent SS from the ABRs could achieve 2-4 mg/L (Fig. 7) and removal rate reached 99% without secondary settling requirement. Though effluents from CMABRs had to go to secondary sedimentation tank for solid and liquid separation, its SS concentrations could only reach 24-128 mg/L with highest removal rate of 62-73% (Fig. 8). Foxon et al. (2006) found that with HRT of 22 h, ABRs could help to reduce SS from 480 ± 109 mg/L in the influents to 225 ± 55 mg/L in the effluents. By varying HRT of ABR from 24, 18, 12 and 8 h, Nast et al. (2008) found that it was able to reach SS removal rate of 82, 73, 70 and 69% respectively and SS could reduced from 158-488 mg/L in the influents to 53, 65, 74 and 78 mg/L in the effluents, respectively.

3.2 Period 2

Organic loading rates (OLR) were increased by reduced hydraulic retention time (HRT) of the reactors. ABR 1' was operated at HRT of 1 h and highest OLR of 4.61-8.06 kg COD/m^3.d. ABR 2' had HRT of 2 h and OLR of 2.30-4.03 kg COD/m^3.d. These values of ABR 3' were 3 h and 1.54-2.69 kg COD/m^3.d. Figure 9 shows that effluent COD of ABR 3' reached 64-80 mg/L, while the values of ABR 2' and ABR 1' were in the range of 96-112 mg/L and 112-128 mg/L, respectively. ABR 3' achieved highest COD removal rate as it was operated with lowest organic loading rate compared to that of ABR 2' and ABR 1'. In other words, it is better to operate the ABR at organic loading rate of 1.54-2.69 kg COD/m^3.d with HRT of 3 h or lower OLR and higher HRT to have better removal rate. This experimental result seems matching with study of Nast et al. (2008). It was found that ABRs operated with OLR of 0.549-0.914 kg COD/m^3.d and HRT of 24 h had COD removal rate of 82% compared to those operated at higher OLR (0.856-2.100 kg COD/m^3.d) and lower HRT (8-18 h). Foxon et al. (2008) and Nast et al. (2008) also found that ABRs operated at OLR of 0.40-2.10 kg COD/m^3.d and HRT of 8-48 h could achieved COD removal rate of 72-82%, corresponding to COD reduced from 505-914 mg/L in the influent to 105-225 mg/L in the effluent. In general, when increasing organic loading rates in the period 2, COD removals of ABRs reached 71-76% with influent COD of about 336 mg/L and effluent COD in the range of 80-96 mg/L, while CMABRs could reach highest COD removal rate of only 62% and COD after settling of 128 mg/L. pH of influents (in the range of 7.27-7.88) and effluents (in the range of 7.12-7.68) were still in the good range for anaerobic microorganisms growth. F/M ratios of these reactors were in the range of 0.06-0.11 kg COD/kg VSS.d.

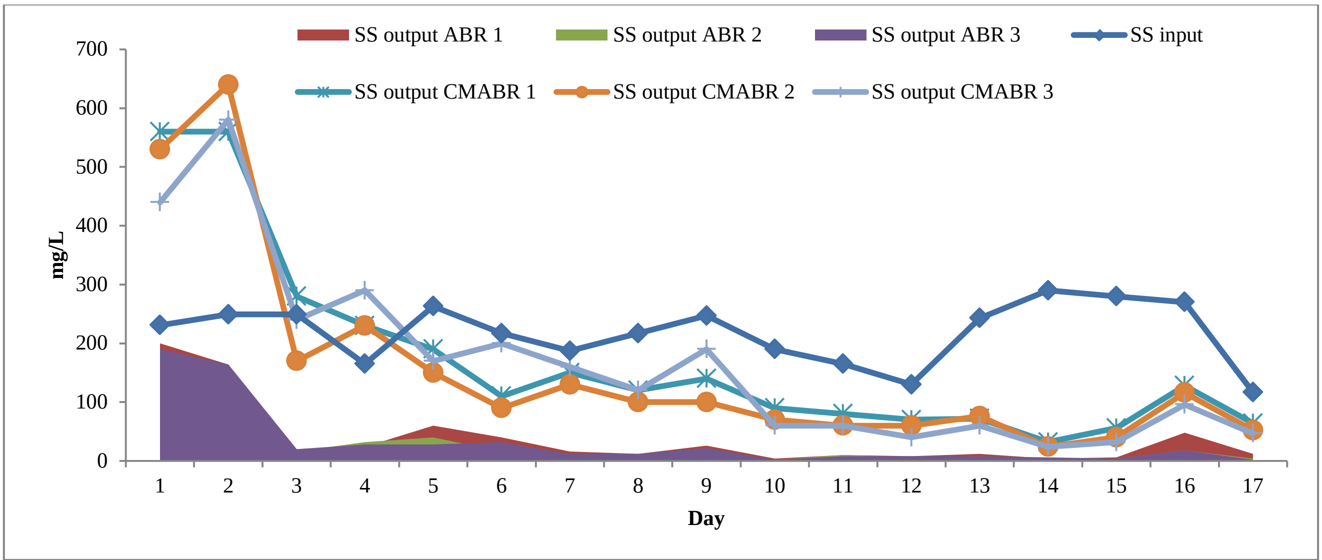

Fig. 7 Change of suspended solid concentrations in the influents and effluents of ABRs and CMABRs.

In this period, suspended solid removal rates of ABRs were still as high as 91-96%. Suspended solid concentrations could reduce from 110-270 mg SS/L in the influent to 12-32 mg/L in the effluent without secondary settling application. Suspended solid removals of ABRs gradually in creased from day 1 to day 6 and reached steady state from day 7 onwards. Compared to ABRs, effluents of CMABRs needed to go through secondary sedimentation tanks and highest SS removal rate was only 88-91% with effluent SS in the range of 30-80 mg/L. It is also important to note that effluent SS concentrations of ABR 1', ABR 2' and ABR 3' were higher than those of ABR 1, ABR 2 and ABR 3. It is attributed to lower HRT of ABR 1', ABR 2' and ABR 3' (1 h, 2 h and 3 h, respectively) compared to those of ABR 1, ABR 2 and ABR 3 (4 h, 5 h and 6 h, respectively). Nasr et al. (2009) also concluded that SS removal rate of ABRs with longer HRT was higher than that of shorter HRT

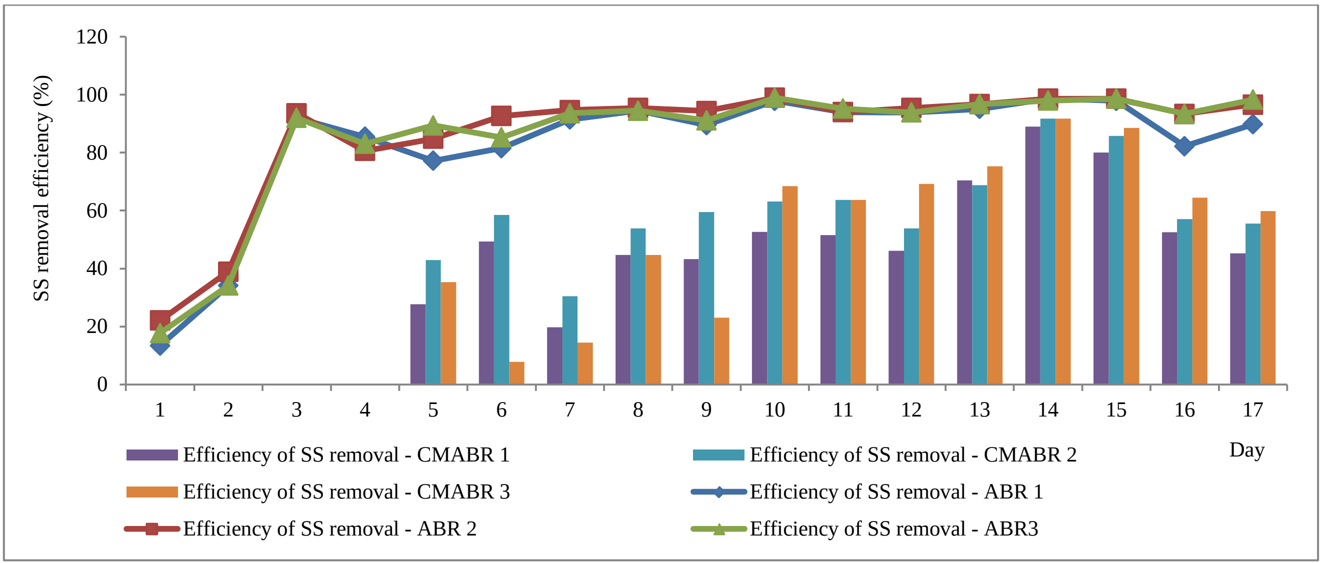

Fig 8 Suspended solid removal efficiencies of ABRs and CMABRs.

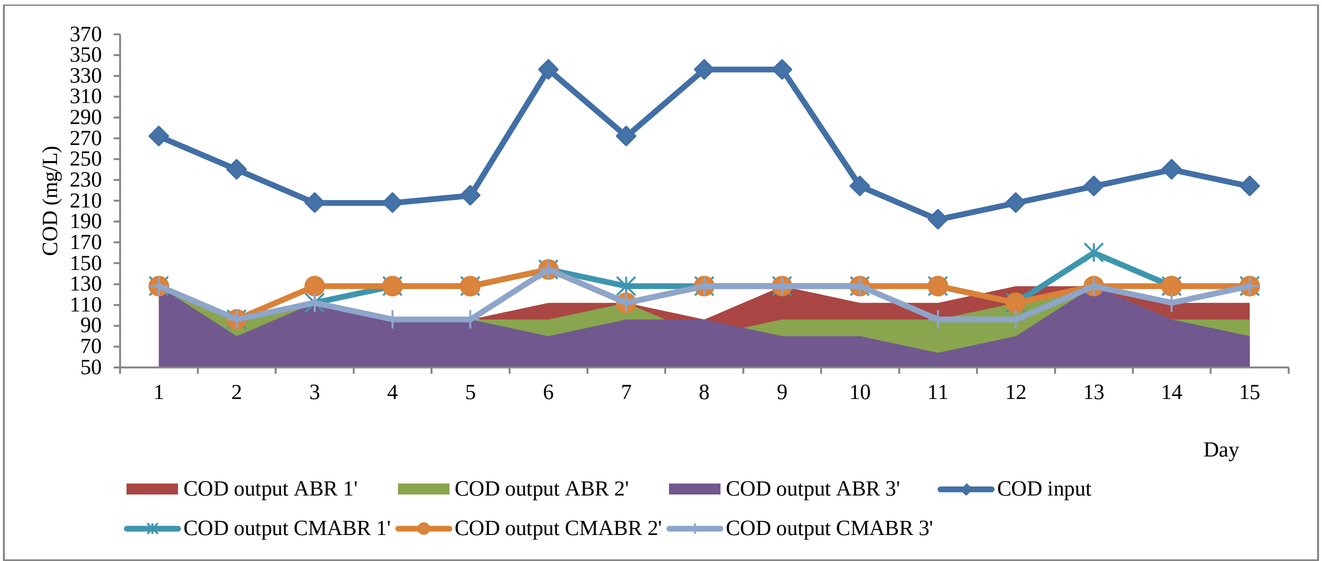

Fig 9 Change of total COD of influents and effluents of ABRs and CMABRs operated in the period 2.

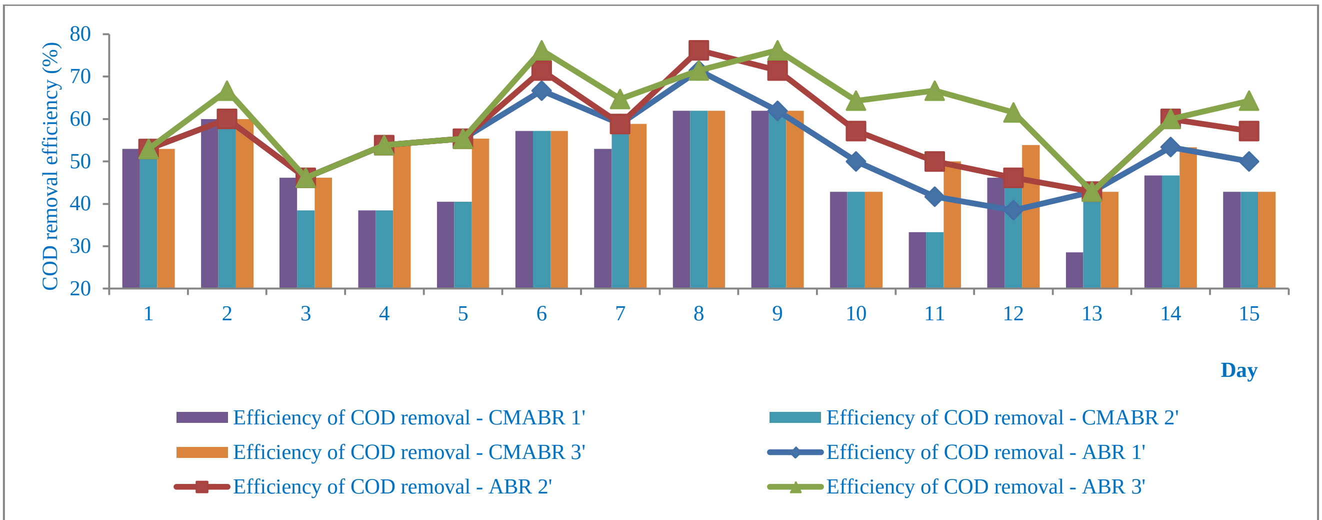

Fig 10 Total COD removal efficiency of ABRs and CMABRs at increased OLRs condition.

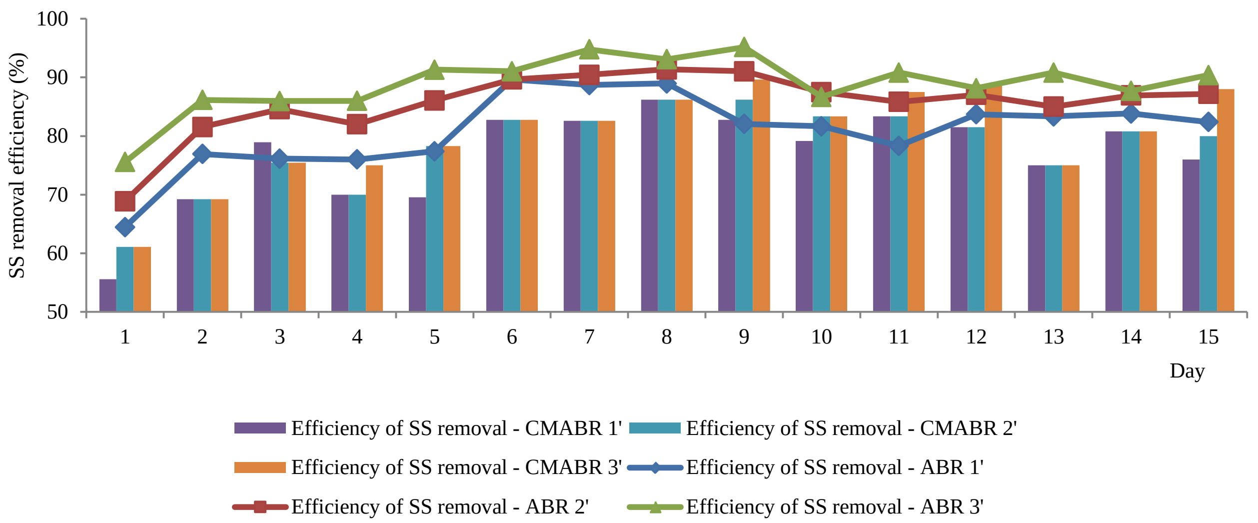

Fig 11 Change of influent and effluent SS of ABRs and CMABRs operated in the period 2.

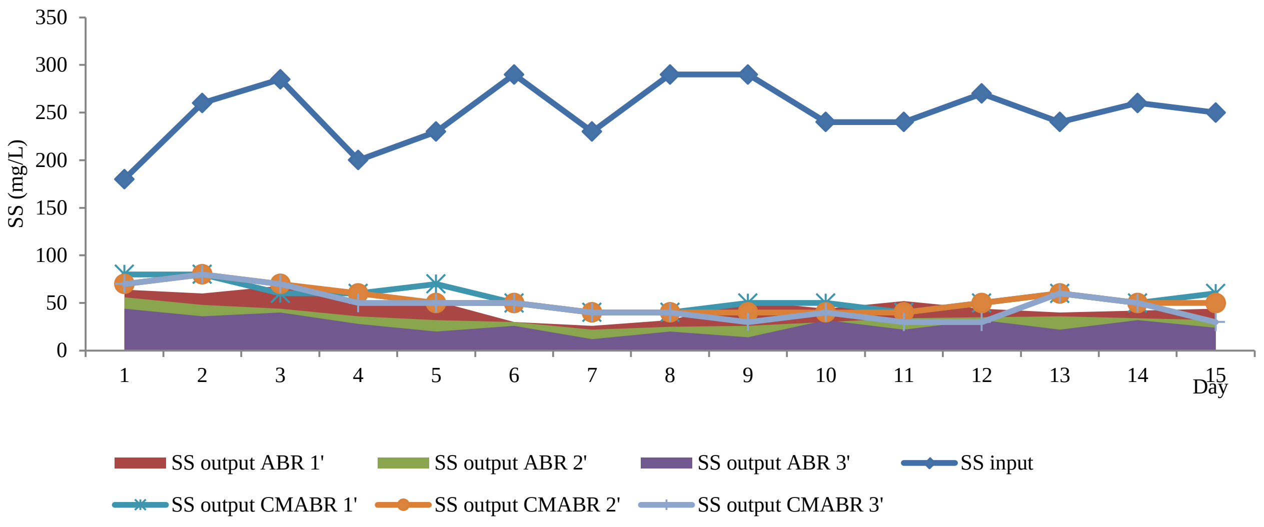

Fig. 12 SS removal rate of ABRs and CMABRs operated in the period 2.

3.3 Suspended solid removal rate of each compartment of ABRs

Suspended solid removals from each compartment of ABRs were evaluated when the reactors reached steady state. Assessment was carried for 4 days by testing SS concentration from effluent of each compartment of the ABR. It was found that SS from influent was removed via passing through each compartment of the reactor. In ABR 1', SS removal of the first two compartments was 41 – 48%, SS reduced from 230 – 250 mg/L to 68 – 92 mg/L and in the next three compartment, SS removal rate reached 7-21% with SS reduced from 68-92 mg/L to 44-56 mg/L. ABR 2' had SS removal of the first two compartments of 42-58%, SS reduced from 230-250 mg/L to 52-68 mg/L, slightly higher than that of ABR 1'. In the next three compartment of the ABR 2', SS removal rate was the same as ABR 1', reached 7-21%, corresponding to effluent SS of 41-54 mg/L. In the ABR 3', SS removal rate of the first compartment was 53-54%, SS reduced from 230-250 mg/L to 108-116 mg/L. Effluent SS of the second compartment of ABR 3' was 24-32 mg/L with removal efficiency of 72-78%. The last compartment of this reactor helped to remove about 33% of the remaining SS. Within this experiment, sludge was kept in the reactors for 32 days without excess sludge removal. Thus, in order to determine optimum solid retention time of ABRs, it is necessary to carry out other researches.

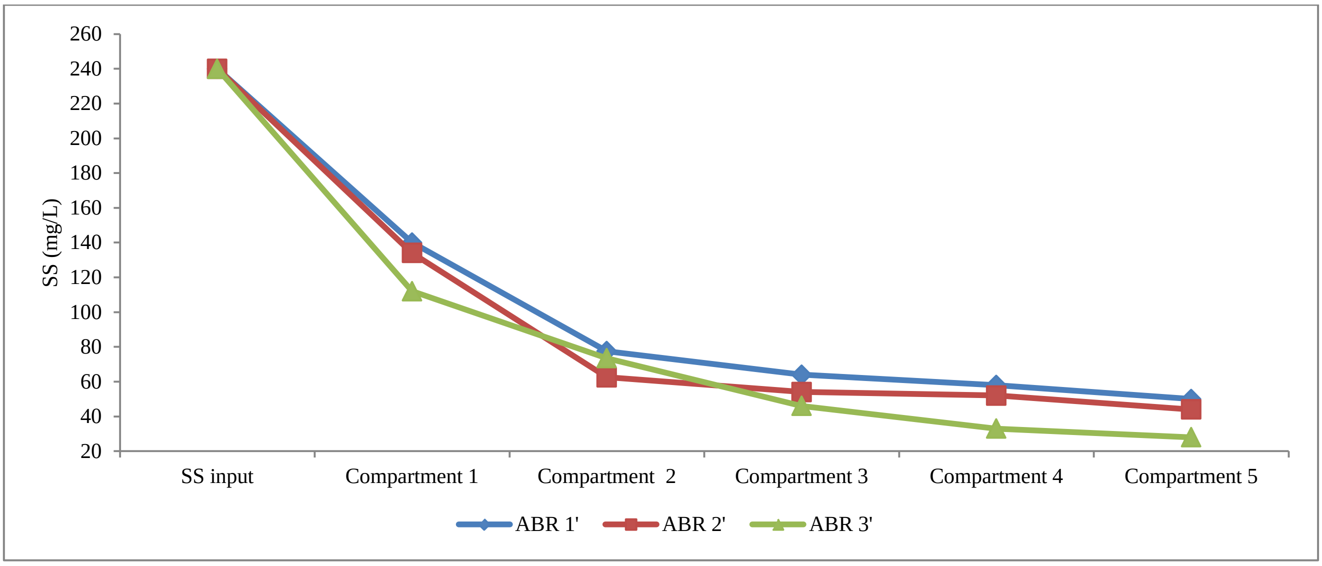

Fig. 13 Change of SS of each compartment of ABR 1', ABR 2' and ABR 3' in the period 2.

4. Conclusions and recommendations

4.1 Conclusions

- It is possible to remove organic matter from domestic wastewater using ABR with 5 compartment at organic loading rate of 1.54-2.69 kg COD/m^3.d, HRT of 3 h and F/M of 0.02-0.04 kgCOD/kg VSS.d. Influent COD of 176-336 mg/L reduced to 64-80 mg/L and removal rate reach 72-74%.

- ABRs could remove suspended solid with efficiency as high as 91-96%. SS reduced from 110-270 mg/L to 12-32 mg/L. Suspended solid was reduced via each compartment of the reactor, especially in the first two compartments.

- It is possible to operate ABR with organic loading rate up to 8.06 kg COD/m^3.d and HRT of 1 h. In this case, COD removal rate reached 62%, COD reduced from 336 mg/L to 128 mg/L.

- CMABRs had lower COD removal efficiency compared to those of ABRs. Highest COD removal reached 62%, COD reduced from 229-251 mg/L to 80-128 mg/L with HRT of 4-5 h, organic loading rate of 0.84-2.02 kg COD/m^3.d and F/M ratio of 0.01-0.03 kg COD/kgVSS.d.

- Sludge concentration of ABRs was controlled in the range of 2,888 – 3,040 mg VSS/L and still remained in the range of 3,002 – 3,220 mgVSS/L at the end of the experiments without discharged. For CMABRs, these values were 2,670 – 3,000 mg/L and 2,860 – 3,350 mg/L, respectively.

4.2 Recommendations

It seems that ABRs would be a promissed technique to removal COD and SS of domestic wastewater with several advantages as acceptable removal efficiency, lower voulme and area requirement, saving energy as no mixing requirement and less number of treatment unit as no secondary sedimentation needed. It is recommended for further testing at pilot scale as well as determination of optimum solid retention time.

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