International Journal of GEOMATE, May, 2017, Vol.12 Issue33, pp. 78-84
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.33.2588

THE ANAEROBIC BAFFLED REACTOR (ABR): PERFORMANCE AND MICROBIAL POPULATION AT VARIOUS COD LOADING RATES

*Sopa Chinwetkitvanich[1] and Apaporn Ruchiraset[1]

[1]Department of Sanitary Engineering, Faculty of Public Health, Mahidol University, Bangkok, Thailand

*Corresponding Author, Received: 17 July 2016, Revised: 01 August 2016, Accepted: 01 Dec. 2016

ABSTRACT: Anaerobic Baffled Reactor (ABR) is one type of high-rate anaerobic reactor equipped with a series of baffles. This baffles plays an important role of biomass retaining, consequently, sludge retention time (SRT) could be operated separately from hydraulic retention time (HRT) without needs of filter or media packing. Three 10-liter laboratory scale ABRs with different compartment numbers (3, 6 and 8 compartments) were operated with constant HRT of 24 hrs. Synthetic carbohydrate-protein wastewater was fed to these reactors with COD loading rate of 4 g COD/l-d. The results evidently showed that the compartmentalized structure of ABR helped retard sludge washout rate. The more compartments, the lower of sludge washout rate was. The ratios of SRT/HRT were found as 35, 73 and 134 d/d in the reactors with three, six and eight compartments, respectively. In addition, COD removal efficiencies were observed with percentages of 74, 78 and 83, respectively. Moreover, studying of the microbial populations by FISH technique proved the existence of microbial phase (methanogens and acidogens) separation in ABR system with six and eight compartments, but not clearly distinguishable in three-compartment ABR.

Keywords: Anaerobic Baffled Reactor, FISH Technique, Methanogens, Acidogens, COD Loading Rates

1. INTRODUCTION

Anaerobic respiration processes have been widely used for biodegradation of wastewater. Their several advantages over other aerobic processes of wastewater treatment have been acknowledged such as energy saving, less biomass production, low construction and operation cost, high removal efficiency and energy as a by-product. Nonetheless, anaerobic process usually has a problem of maintaining biomass within reactor. A conventional digester has usually been operated with solid retention time (SRT) equal to hydraulic retention time (HRT). Therefore, in order to keep the biomass within the reactor as long as possible, high volume of reactor is necessary. Subsequently, several modifications to solve this problem were attempted, such as returning the biomass into the reactor, using a filter or media for trapping the biomass in the reactor. However, the cost of filter and packing material becomes the disadvantage. Moreover, the latest anaerobic configuration, UASB (upflow anaerobic sludge blanket) is able to undertake high organic loading rate wastewater with great success, but sludge granulation is too complicated to achieve. Besides, methanogens in UASB was sensitive to fluctuation of wastewater composition [1].

An anaerobic baffled reactor (ABR) is a high-rate anaerobic reactor using a series of vertical baffles to direct the flow upward and downward from inlet to outlet. ABR has a higher resistance of both hydraulic and organic shock loads than some anaerobic processes. ABR can be designed to improve biomass retention in reactor, resulting in a longer SRT [2], [3] without need of packing media or a solid-settling chamber or sludge granulation. The compartmentalized structure in ABR is an important key of retaining biomass within the reactor. The more compartments in a reactor, the better biomass retention is. Also, this structure is helpful in separating acidogenic and methanogenic phases, which will enhance stability and higher organic loading rate (OLR) of the anaerobic process, as well as, increase the overall removal efficiency with shorter HRT [4]. Several studies have found that the ABR could be operated with HRT less than 1 day [5], [6]. The successful operation of ABR in treating of domestic, industrial and agricultural wastewater with the removal efficiency higher than 90% were reported [7]-[11].

Although ABR has been developed for over twenty years, the knowledge in designing such a reactor has still not been much clarified. The most advantage of ABR is its SRT and HRT can be operated separately. Therefore, SRT can be increased over HRT several times. This will benefit in a smaller size of reactor while still achieving high biomass concentration and consequently high performance. The SRT/HRT ratio is an important parameter to compare the effectiveness of ABR technically and economically. The aim of this study is to study effect of compartment numbers on SRT/HRT ratios and appropriate OLR for treating carbohydrate-protein wastewater.

2. MATERIALS AND METHODS

2.1 Laboratory Scale Reactors

A schematic diagram of experimental setup was shown in Fig. 1. Three laboratory-scale ABRs were made of clear acrylic with the detail and dimension of reactors as shown in Fig. 2. All three reactors were having ten liters effective volume and most of the components are similar. The difference was the number of compartment consisted in each reactor, which three, six, and eight compartments were applied for this study.

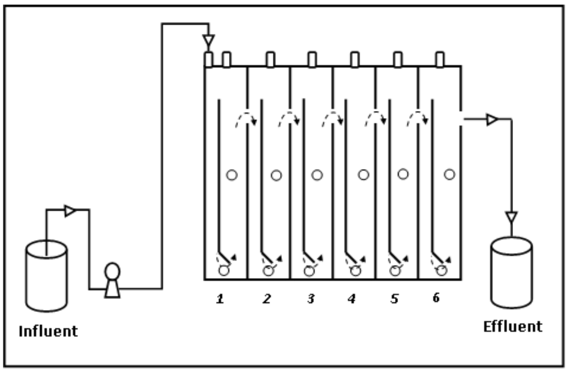

Fig. 1 A schematic diagram of experimental setup (6-compartments).

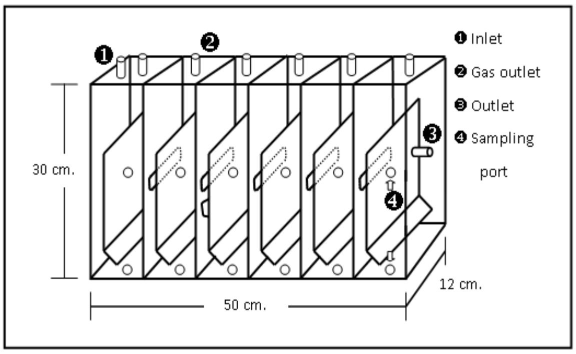

Fig. 2 Details and dimension of experimental reactor (6-compartments).

Each compartment had a vertical baffle that directs the liquid flow alternately downward and upward. The ratio of down-flow and up-flow width in each compartment was 1:3 as suggested by Dama et al. [10]. Also, the 45-degree slanting baffle was recommended to reduce the region of dead space and direct the flow to the center of the up-flow region [10]. The wastewater flows from one compartment to the next through window cut on the acrylic partition. The gas outlets are on the upper part of the reactor and sampling ports are at the side.

2.2 Seeding and Acclimatization

The systems were inoculated with anaerobic sludge from ABR treating swine wastewater for approximately three months. Each reactor was seeded with initial MLSS of about 28 g/l, then; they were allowed to settle for about two days. For acclimatization, synthetic carbohydrate-protein wastewater containing a designate strength was fed with an operating HRT of 80 hrs, which was suggested for high stability and COD removal [12]. Then, it was gradually decreased to the designated HRT of 24 hrs. All reactors were operated until a steady state was reached.

2.3 Experimental Design

This experiment was divided into two parts; the first part was conducted with three reactors equipped with three, six and eight compartments, named as 3C-OLR4, 6C-OLR4, and 8C-OLR4, respectively. They were all operated with OLR of 4 g COD/l-d and HRT of 24 hrs. The second part was operated with three more different OLRs of 8, 12 and 16 g COD/l-d using reactors with a certain compartment number. According to the results from the first part, the eight-compartment reactor showed the most appropriate reactor for overall performance. Hence, six experiments were conducted with operating conditions as detailed in Table 1.

Table 1 The operating conditions in this study.

Exp. names	No. of compar tments	COD (mg/l)	HRT (hrs)	OLR (g COD/ l-d)
Part I: Effects of compartment numbers				
3C-OLR4	3	4,000	24	4
6C-OLR4	6	4,000	24	4
8C-OLR4	8	4,000	24	4
Part II: Optimum organic loading rate.				
8C-OLR8	8	8,000	24	8
8C-OLR12	8	12,000	24	12
8C-OLR16	8	16,000	24	16

2.4 Analytical Methods

Samples were regularly collected by grab sampling method. Influent and effluent sample were collected from storage container. Supernatant of each compartment was collected from sampling ports as shown in Fig.2. The parameters of total COD (tCOD), soluble COD (sCOD), Alkalinity, TSS, VSS, pH, and ORP were determined in accordance with Standard Methods for the Examination of Water and Wastewater [13]. Biogas was collected and counted by gas meters using water displacement method. Bacterial community was determined by FISH technique.

3. RESULTS AND DISCUSSION

3.1 Part I: Effects of Compartment Numbers

3.1.1 Performance in COD removal

Average influent COD levels fed into 3C-OLR4, 6C-OLR4, and 8C-OLR4 experiments were 4,050, 4,230, and 4,230 mg/l, respectively. The pH values of the feeds were 8.2, 8.1, and 8.1 with prepared alkalinity of 2,220, 2,040, and 2,040 mg/l as $CaCO_3$, respectively. Figure 3 illustrated that COD removal efficiencies during high HRT of 80 hrs were quite high (>80% removed) in all ABRs. The lower HRT, the lower COD removal appeared, due to low HRT might induce channeling occurrence, resulting in less contact between sludge and substrate, as well as higher sludge washout.

Average COD removal efficiencies during a steady state of 74, 78 and 83% were found in 3C-OLR4, 6C-OLR4 and 8C-OLR4 experiments, respectively. In addition, COD utilization rates were averagely 29.8, 32.8, and 35.0 g/d, respectively. This could be said that more compartments could enhance COD utilization rate. Moreover, HRT adjusting during acclimatization (especially decreasing HRT or increasing OLR) affected COD removal efficiency more dramatically in less compartment number reactor. The ABR with more compartment numbers exhibited higher tolerability to hydraulic change.

In addition, a profile of soluble COD values in every compartment of each reactor (data not shown here) illustrated that COD was mostly removed in the first compartment (40 – 58%), then, slightly decreased throughout the reactor.

3.1.2 pH values and microbial phase separation

Lengthwise increasing pH was observed throughout the reactors, which microbial phase separation in ABR could be implied. The front of reactor acts like an acidogenic phase, and the latter performs as methanogenic phase. However, a phase separation was not obvious in the 3C-OLR4 experiment where little different pH values occurred among its three compartments (6.8, 6.9, and 7.1, respectively). Anyway, phase separation was more evident in other two experiments (6C-OLR4 and 8C-OLR4), especially in consideration of pH values. That is, pH values in the first and the last compartments of a 6C-OLR4 experiment were 6.8 and 7.5, while those of 8C-OLR4 experiment were 6.5 and 7.7. It appears that more compartments in a reactor could induce the proper environment for two- phase anaerobic operation.

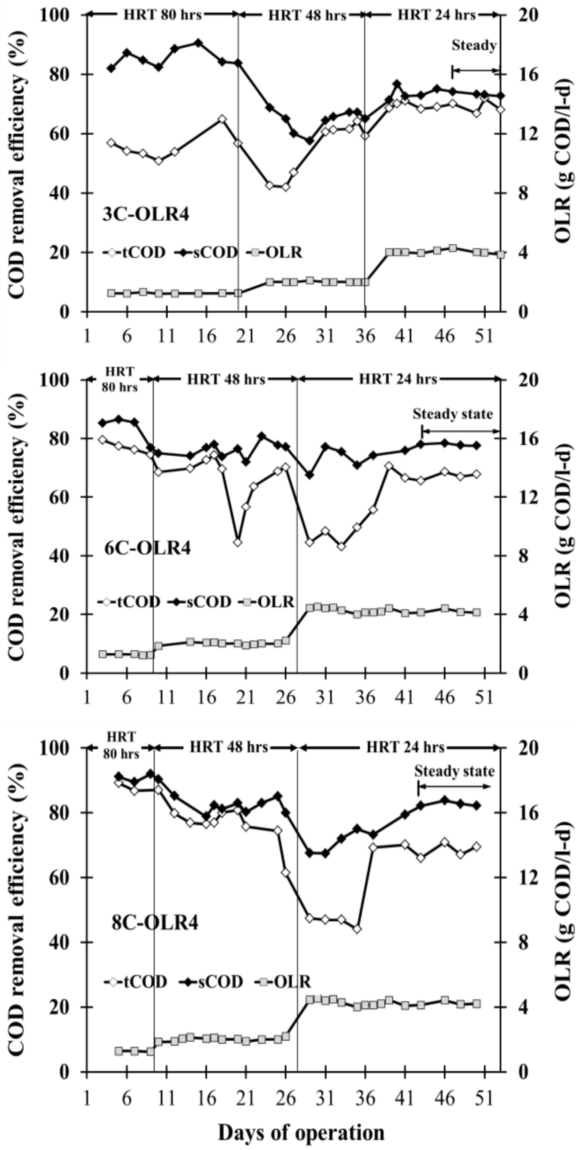

Fig. 3 COD removal efficiencies and OLRs of the Part I experiments.

3.1.3 Sludge mass balance

Figure 4 shows a component of sludge mass balance in Part I experiments based on initial sludge concentration of around 28 g TSS/l inoculated into 10-litre reactors. Initial sludge mass in reactors 3C-OLR4, 6C-OLR4, and 8C-OLR4 were calculated at 288, 273 and 276 g TSS, respectively. Effluent suspended solids (SS) were regularly analyzed and used for total sludge washout calculation. Total mass of sludge washout were 269, 205 and 110 g TSS, while final sludge mass of 99, 159 and 257 g TSS resided at the end of experiments, respectively. According to mass balance, produced sludge mass were calculated at 79, 90 and 91 g TSS, respectively. Observed yield in all reactors were obtained at 0.04 g VSS/g COD.

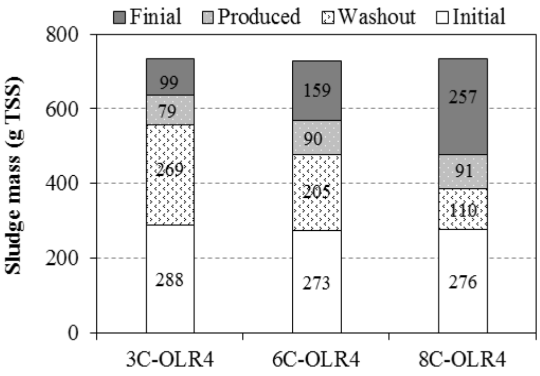

Fig. 4 Sludge component in consideration of different compartment numbers (Part I).

Sludge produced in the reactor 3C-OLR4 was significantly lower than the other two (6C-OLR4 and 8C-OLR4). It could be due to larger compartment in a three-compartment reactor than six- and eight-compartment reactors. Though the recommended ratio of up-flow and down-flow width of 1:3 was installed in all reactors, more dead-space still occurred in a three-compartment reactor, and could reduce contact opportunity between sludge and substrate. Also, the mixing in six- and eight-compartment reactors was visually better.

As mention above, one may conclude that the number of compartment affects on maintainability of sludge within ABRs, the more compartment numbers, the lower sludge washout rate is and the higher sludge resides in the reactor. Also, higher SRT and SRT/HRT ratio were observed in reactors equipped with more compartment numbers as shown in Fig. 5.

The SRT/HRT ratios achieved in this study evidently showed that SRT and HRT could be separately controlled under ABR configuration. These SRT/HRT ratios (Fig.5) were similar to those of ABRs reported elsewhere [5], but still could not compete with that found in UASB configuration reactors [14]. However, the complexity of UASB reactor design and its operation might cause grave concern. Nonetheless, lower SRT/HRT ratios in ABRs were sometimes reported, especially when treating high solid content associated with low biodegradability wastewater [15].

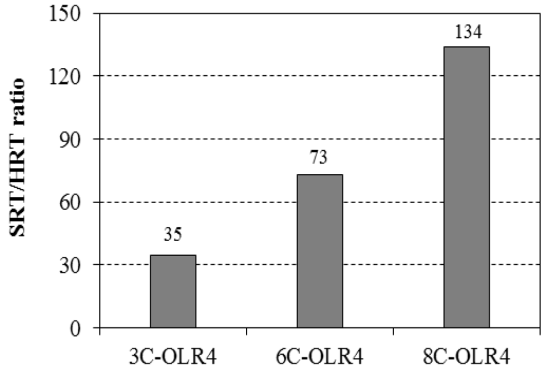

Fig. 5 SRT/HRT ratios in consideration of different compartment numbers (Part I).

3.2 Part II: Optimum Organic Loading Rate

3.2.1 Performance and microbial phase separation

According to the results from previous experiments (Part I), eight-compartment ABRs were selected for this experimental part (Part II). COD content in synthetic wastewater were adjusted to obtain designated OLRs as shown in Fig.6. Average influent COD in the experiments of 8C-OLR8, 8C-OLR12, and 8C-OLR16 were at 8,300, 12,463 and 16,301 mg/l, respectively. Averages of influent pH were 8.3, 8.3, and 8.5, as well as, of alkalinity were 2,148, 1,963, and 2,606 mg/l as $CaCO_3$, respectively.

Figure 6 shows that average COD removal efficiencies achieved during a steady state of the experiments 8C-OLR8 and 8C-OLR12 were 96 and 88%, respectively, which were similar to one of 8C-OLR4 experiment (83%) mentioned in the previous part. For the experiment of OLR at 16 g COD/l-d (8C-OLR16), resided sludge from the experiment with OLR of 8 g COD/l-d was inoculated. During the acclimatization, this reactor with the OLR of 8 g COD/l-d showed COD removal efficiencies near 90% level. After final adjustment of the OLR up to 16 g COD/l-d, COD removal efficiency rapidly decreased to 34% level within a week and failure eventually appeared.

More acidic pH values of 5.4 and 5.7 were observed in the first compartments of the 8C-OLR8 and 8C-OLR12 while neutral pH of 7.8 and 7.3 were still maintained in the last compartment. It is possibly believed that microbial phase separation was more obvious when operating OLR increased.

3.2.2 Sludge mass balance

Similarly, initial sludge concentration of around 28 g TSS/l was inoculated into every reactor. After reaching a steady state, sludge component of every experiment with eight-compartment was analyzed and exhibited in Fig.7 (Note: result of the 8C-OLR4 was referred from previous part). Total sludge washout and final sludge mass of the 8C-OLR4, 8C-OLR8, 8C-OLR12 and 8C-OLR16 experiments were 110, 144, 168 and 206 g TSS, as well as 257, 256, 321 and 378 g TSS, respectively. In addition, produced sludge mass were calculated at 91, 122, 201 and 308 g TSS, respectively.

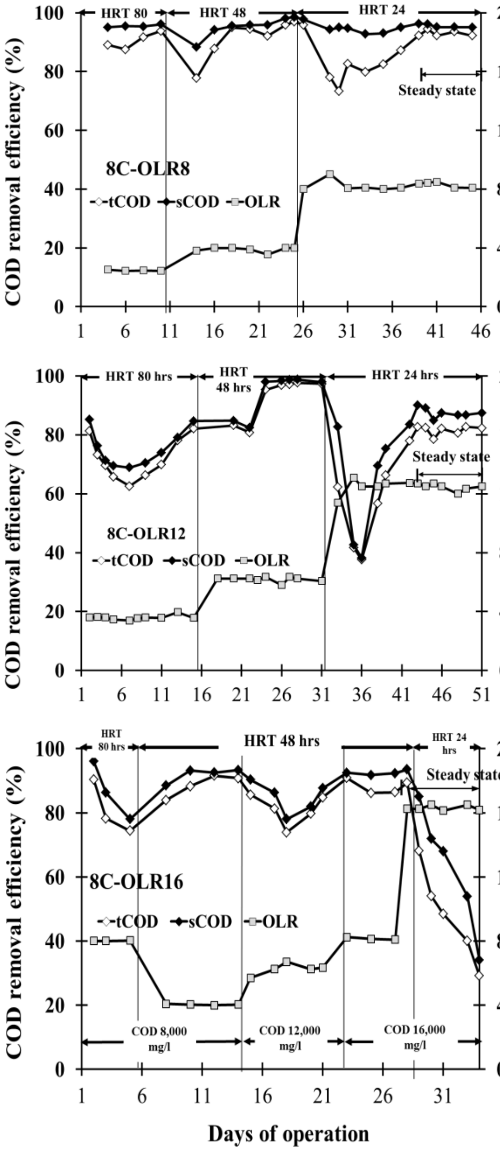

Fig. 6 COD removal efficiencies of the Part II experiments.

Although these ABRs were equipped with the same number of compartment, the SRT and SRT/HRT ratios were not similar. It can be seen that the different OLRs affected on the SRT/HRT ratios, higher OLR resulted in lower SRT/HRT ratio as shown in Fig.8. The explanation should be that higher OLRs resulted in more biogas production, consequently, rising biogas enhanced turbulence in sludge bed. Therefore, total sludge washout mass (g TSS) accordingly increased when OLRs were raised. However, sludge mass and a SRT/HRT ratio of the 8C-OLR16 must be remarked that they were calculated from only 34 days of operation before failure.

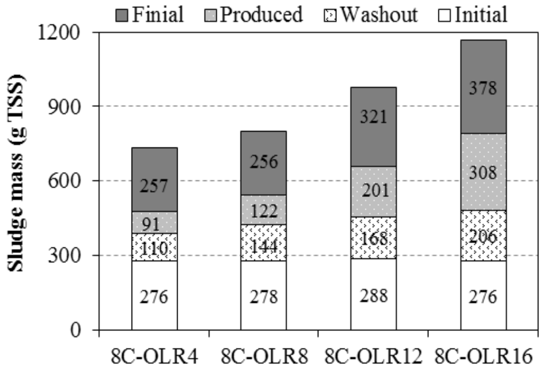

Fig. 7 Sludge component in consideration of different OLRs (Part II).

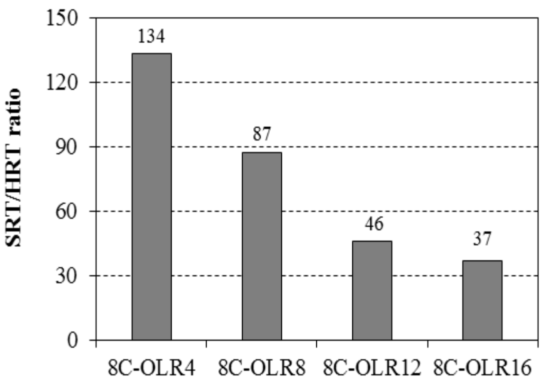

Fig. 8 SRT/HRT ratios in consideration of different OLRs (Part II).

3.3 Fluorescence In Situ Hybridization (FISH)

The microbial populations were studied by FISH technique using probe EUB338 labeled with FITC (green) for domain Eubacteria, which acidogens belong to this bacterial group. Also, probe ARC915 labeled with CY3 (red) was used for domain Archaea, which methanogens were categorized into this group. DAPI (blue) staining was applied to determine total cell bacteria. Figure 9 shows FISH images of the 3C-OLR4 experiment.

The ratio of acidogens (EUB338 probed; green color) to total bacteria cell (DAPI stained; blue color) were quite similar to the ratio of methanogens (ARC915 probed; red color) to total bacteria cell (DAPI stained; blue color) in every compartment (C1, C2 and C3). This could be stated that the populations of methanogens and acidogens were almost identical throughout the

ABR. Three compartments could not stimulate microbial phase separation in this case. This was consistent to the mentioned pH values of 6.8, 6.9 and 7.1 in C1, C2 and C3, respectively. It was obvious that three compartments could not promote the microbial phase separation.

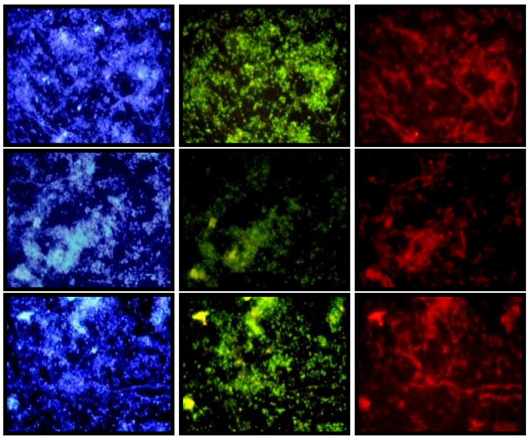

Fig. 9 DAPI-staining/epifluorescence micrographs of microbial cells **3C-OLR4** experiment; Left: DAPI staining, Middle: Bacterial cells hybridized with FITC-labeled EUB338, and Right: Archaeal cells hybridized with Cy3-labeled ARC915.

In case of eight compartments, lengthwise difference of microbial population in the ABR was revealed in Fig. 10. The ratio of acidogens and methanogens in each compartment of the 8C-OLR8 experiment was visually estimated at 90:10 in the first compartment. Since the second compartment, acidogens were relatively lower than methanogens, especially in the last two compartments (C7 and C8) that acidogens were greatly less than methanogens. Similarly, FISH results of the experiments 8C-OLR12, and 8C-OLR16 (data not shown here) also illustrated compartmentalized change of microbial population. Increased OLRs (up to 16 g COD/l-d) did not affect microbial phase separation in this study.

Acidogens (EUB338 probed; green) was a prominent group in the front compartment while methanogens (ARC915 probed; red) was in the rear compartments. Thus, it is interesting to note that acidogenic phase was evident in the first three compartments where low pH values between of 5.4-6.7 occurred. Whereas methanogenic phase was manifested in the last four to five compartments (pH values were about 7.0-7.8). In addition, the visual observation of sludge in different compartments exhibited that sludge in the first three compartments was more whitish, while those in the latter compartments were more blackish. This was similar to a study [16] mentioning about blackish color of methanogenic phase.

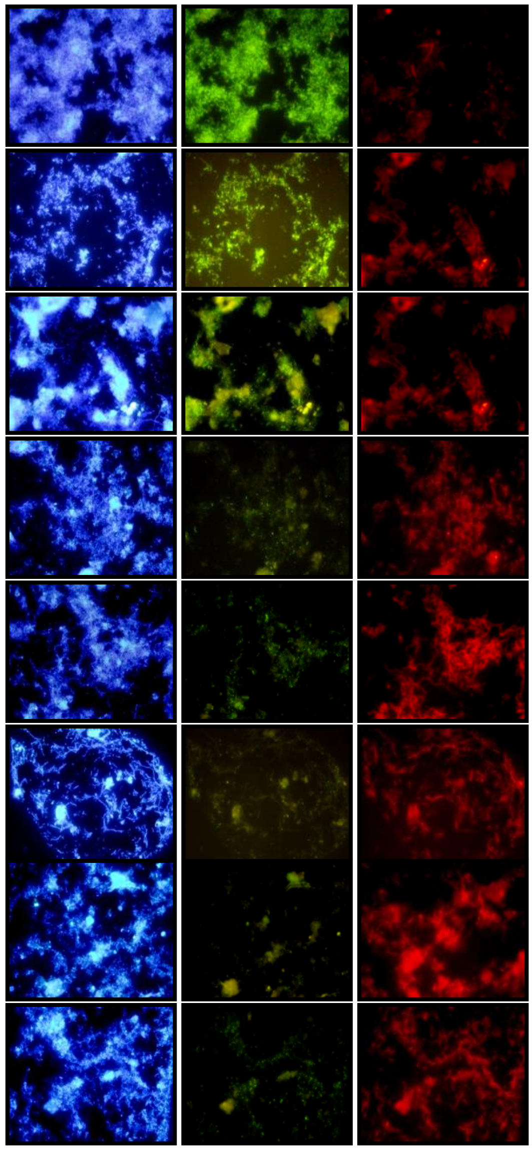

Fig.10 DAPI-staining/epifluorescence micrographs of microbial cells 8C-OLR8 experiment; Left: DAPI staining, Middle: Bacterial cells hybridized with FITC-labeled EUB338, and Right: Archaeal cells hybridized with Cy3-labeled ARC915.

4. CONCLUSION

The compartmentalizing configuration is an important factor affecting on SRT/HRT ratio. More compartments help retarding sludge washout, resulting in higher SRT with smaller HRT. Consequently, high COD removal efficiency was obtained by using eight-compartment ABR. Though microbial phase separation was not obvious in three-compartment ABR, fair COD removal efficiency (over 70%) was still achieved. Eight-compartment ABR could handle operating OLRs up to 12 g COD/l-d and still provided COD removal efficiency higher than 80%, especially for

ABR treating low solid content wastewater.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge assistance for FISH technique from Dr. Somkiet Techkarnjanaruk, National Center for Genetic Engineering and Biotechnology of Pilot Plant Development and Training Institute, KMUTT. This article was financially supported for publication by the China Medical Board (CMB), Faculty of Public Health, Mahidol University.

6. REFERENCES

[1] Chafiq T, "Doses regulation in anaerobic treatment of wastewater: The case of Moroccan paper industry" International Journal of Geomate, Vol. 10, No. 2 (Sl. No. 20), 2016, pp. 1751-1755.

[2] Nachaiyasit S, Stuckey DC, "The effect of shock loads on the performance of an anaerobic baffled reactor (ABR): 1, step changes in feed concentration at constant retention time" Water Research, Vol 31(11), 1997, pp. 2737-2746.

[3] Nachaiyasit S, Stuckey DC, "The effect of shock loads on the performance of an anaerobic baffled reactor (ABR): 2, step and transient hydraulic shocks at constant feed strength" Water Research, Vol 31(11), 1997, pp. 2747-2754.

[4] Demirer GN, Chen S, "Two-phase anaerobic digestion of unscreened dairy manure" Process Biochemistry, Vol 40(11), 2005, pp. 3542-3549.

[5] Grobicki A, Stuckey DC, "Performance of the anaerobic baffled reactor under steady-state and shock loading condition" Biotechnology and Bioengineering, Vol 37, 1991, pp. 344-355.

[6] Bell J, Buckley CA, "Treatment of a textile dye in the anaerobic baffled reactor" Water SA, Vol 29(2), 2003, pp.129-134.

[7] Ahamed A, Chen CL, Rajagopal R, Wu D, Mao Y, Ho IJR, Lim JW, Wang JY, "Multi-phased anaerobic baffled reactor treating food waste" Bioresource Technology, Vol 182, 2015, pp. 239-244.

[8] Pirsaheb M, Rostamifar M, Mansouri AM, Zinatizadeh AAL, Sharafi K, "Performance of an anaerobic baffled reactor (ABR) treating high strength baker's yeast manufacturing wastewater" J. of the Taiwan Institute of Chemical Engineers, Vol 47, 2015, pp.137–148.

[9] Zhu GF, Li JZ, Wu P, Jin HZ, Wang Z, "The performance and phase separated characteristics of an anaerobic baffled reactor treating soybean protein processing wastewater" Bioresource Technology, Vol 99, 2008, pp. 8027–8033.

[10] Dama P, Bell J, Foxon KM, Brouckaert CJ, Huang T, Buckley CA, Naidoo V, Stuckey D, "Pilot-scale study of an anaerobic baffled reactor for the treatment of domestic wastewater" Water Science and Technology, Vol 46(9), 2002, pp. 263-270.

[11] Bell J, Plumb JJ, Buckley CA, Stuckey DC. "Treatment and decolorization of dyes in an anaerobic baffled reactor" J. of Environmental Engineering, 2002, 1026-1032.

[12] Barber WP, Stuckey DC, "The influence of start-up strategies on the performance of an anaerobic baffled reactor" Environmental Technology, Vol 19, 1998, pp. 489-501.

[13] APHA; AWWA; WEF, "Standard Methods for the Examination of Water and Wastewater, 22nd Ed.; Rice EW, Baird RB, Eaton AD, Clesceri LS, Eds.; American Public Health Association; Washington D.C., USA, 2012.

[14] Singh KS, Viraraghavan T, "Impact of temperature on performance, microbiological, and hydrodynamic aspects of UASB reactor treating municipal wastewater" Water Science and Technology, Vol 48(6), 2003, pp. 211-217.

[15] Boopathy R, "Biological treatment of swine waste using anaerobic baffled reactors" Bioresource Technology, Vol 64, 1998, pp.1-6.

[16] Demirel B, Yenigun O, "Two-phase anaerobic digestion processes: a review" J. of Chemical Technology and Biotechnology, Vol 77(7), 2002, pp. 743-755.