Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.26235

196 (2020) 439–446
August

The role of pH in the degradation of organic substances of institutional wastewater in a compartmentalized anaerobic migrating blanket reactor

C. Aruna*, N. Sivaraman, B. Asha

Department of Civil Engineering, Annamalai University, Annamalai Nagar, India, emails: arunacm100@gmail.com (C. Aruna), sivaramenv@gmail.com (N. Sivaraman), ashrasgo@rediffmail.com (B. Asha)

Received 11 December 2019; Accepted 9 June 2020

ABSTRACT

A laboratory-scale experimental setup was performed to construct a compartmentalized-anaerobic migrating blanket reactor (AMBR) in order to treat the wastewater generated from an institution with every compartment capacity being 14.55 L. Both suspended as well as attached growth processes were accomplished in the reactor. The researcher analyzed the pH level of every compartment. Further, the impact of pH in the development of acidogenic and methanogenic organisms in terms of reduced organic substance was also assessed. With regular intervals in hydraulic retention times such as 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 5.0, and 6.0 d, the complete experiments were conducted with three sets of average influent chemical oxidation demand viz 876, 764, and 660 mg/L. The study estimated the anaerobic pathway from the first to the fifth compartment with regards to a reduction in chemical oxygen demand (COD) due to pH impact. The low pH in the first two compartments, that is, 6.7 and 5.9 led to the reduced methanogenic community for metabolism whereas, in the same compartments, a minimum amount of biogas of 0.016 and 0.019 m^3 of gas/kg COD removed was produced with less efficient COD removal of 50.60% in the first compartment and 40.79% in the second compartment. The fourth and fifth compartments had high pH values, due to the metabolism process that occurred in the methanogenic state in the fifth compartment was 77.01% of COD removal efficiency and 0.088 m^3 of gas/kg COD removed and 75.86% of COD removal efficiency and 0.079 m^3 of gas/kg COD removed in the fourth compartment. From the results, it was inferred that the pH has a profound effect on the experiments conducted in AMBR.

Keywords: Acidogenesis; Anaerobic migrating blanket reactor; Chemical oxidation demand; Hydraulic retention time; Methanogenesis; pH

1. Introduction

Global requirements for potable water have increased in the past few decades which in addition to climate change, result in the increased need for recycling of the wastewater [1,2]. A wide range of wastewater treatment technologies has been developed by many researchers. An anaerobic wastewater treatment technology has gained significant awareness among the researchers and sanitary engineers primarily due to its economic advantages over the aerobic process. The anaerobic migrating baffled reactor (MBR) seems to be a promising candidate among the available high-rate anaerobic reactors, to be used in treating the wastewater in an institutional setting. The anaerobic baffled reactor (ABR) was developed by a modified version of up-flow anaerobic sludge bed blankets [3], in this design, there exists a row of vertical baffles in which the wastewater is forced to flow up and down the arranged compartments that contain mixed anaerobes which are passed from the inlet to the outlet [4]. In the year 2000, the ABR has the most notable advantage, that is, it can longitudinally segregate the acidogenesis and methanogenesis down

* Corresponding author.

Presented at the First International Conference on Recent Trends in Clean Technologies for Sustainable Environment (CTSE-2019), 26–27 September 2019, Chennai, India

1944-3994/1944-3986

the reactor [5]. Various researchers agreed that ABR is the most promising system that can be used to treat industrial wastewater [3,6–9]. The bacteria present inside the reactor rise and settle in a gentle fashion due to both gas production and its flow characteristics, though at the downside of the reactor, it moves slowly [10]. Due to this slow movement, various bacterial groups are allowed to grow under favorable conditions. This way, the reactor acts as if it has a dual mechanism without undergoing high cost-control problems. The two-phase operations that occur in the reactor enhance both methanogenic as well as acidogenic activities. When the wastewater is treated in low temperatures, the low biodegradable substrates undergo hydrolysis at the front end of the reactor due to compartmentalization and the presence of low pH. Constructed in a simple design, the ABR maintains a high void volume and there is no need for high-cost incurring filter media. Further, there is no need for a purposive gas collection or sludge separation systems. The fourth and fifth chambers of ABR are highly efficient in the conversion of solids and biogas when contrasted with the second and third chambers [11]. With a simple construction design, it has a drawback, that is, the operating hydraulic and organic shock loads impact the treatment efficiency.

There is no need for a high amount of maintenance or operational attention for the reactor since it has a good solid retention capacity [12]. The sludge is made up of microbial granules that resist being washed along with the flowing water because of its weight. The baffles also prevent this scenario. These microbes in the sludge degrade the organics present in the flowing wastewater. Due to this anaerobic degradation, the reactor produces methane, and carbon dioxide gases. The anaerobic digestion in ABR is accomplished by two groups of microorganisms in which the first one is acidogenic, which converts complex polymer substrates into simple sugars, alcohols, organic acids, hydrogen, CO_2, and acetate [13,14]. The second group is methanogens that convert simple compounds that are formed in the previous step into methane [15,16]. ABR ensures that there is no risk of clogging and the sludge bed expansion of UASB and anaerobic filter [17]. Having discussed earlier, the ABR comes with numerous advantages such as cheap cost equipment, design simplicity, low amount of sludge production, low operating, and capital cost and finally high treatment efficiency [18–20]. The performance of anaerobic migrating blanket reactor (AMBR) with different wastewater was also well-demonstrated by various authors [21–23]. The primary objective of this research article is to evaluate the role played by pH in the performance of the AMBR for the degradation of chemical oxidation demand (COD) in a compartmentalized anaerobic reactor. The novelty of this research work is to implement the suspended as well as the attached growth system in a single reactor and also bifurgate the acetogenesis and methanogenesis.

2. Experimental methodology

In this research work, a laboratory-scale reactor was fabricated using Plexiglass with 68.25 L working volume and was installed at the Advanced Environmental Laboratory, Department of Civil Engineering, Annamalai University [24]. There were five compartments present in the model with 3 cm distance from the water level and the upper edge of the baffles which is present between the ascending and descending compartments. Three compartments were accomplished with a suspended growth process whereas rest were with the attached growth process. The biocarriers were filled randomly in fourth and fifth compartments. The biocarriers (figino spirals) have high surface adsorption capacity and affinity to microorganisms enabling the adsorption of pollutants and very fast colonization, supported by microbial affinity and the water-binding capacity of the carrier [25]. When the baffles are properly constructed, it allows the wastewater to flow through the sludge bed in a bottom-up fashion. The reactor was equipped with inlet and outlet ports in order to equally distribute the influent wastewater throughout the width of the reactor and minimize the dead space. Apart from the inlet and outlet ports, two ports were provided for each compartment in order to collect the wastewater and sludge. Fig. 1 represents the scheme of the experimental setup whereas Fig. 2 shows the picture of the bio carriers. The physical features and process parameters of experimental models are tabulated in Table 1. The different pH profiles indicate the degree of different phases that got created inside the reactor. Chemical oxygen demand (COD) was analyzed by COD multiphotometer with the ranges mentioned in the meter and the reagents given by the instrument. Volatile fatty acid (VFA) was calculated by the collected condensate water by titration method.

2.1. Characterization of institutional wastewater

The researchers collected the institutional wastewater from the treatment unit that is functioning at Annamalai University located at Chidambaram, Tamil Nadu. The samples were made to handled and characterized as per the procedure formulated by APHA [26] and are tabulated in Table 2.

3. Result and discussions

3.1. Acclimatization process

In the beginning, the acclimatization of the biomass was performed to new environmental conditions such as reactor configuration, temperature, and substrate operating strategies. At the site of the treatment unit mentioned earlier, the source of the inoculum granular sludge was collected from the active anaerobic sludge. Then the granules were made to pass via screening in order to get rid of debris. The reactor was then fed in a continuous manner with municipal sewage via a peristaltic pump (PP-30 EX) so that the reactor functions. For every 3 d, the influent, as well as effluent samples, were collected from the reactor and analyzed immediately. In the beginning, the influent was collected from municipal sewage plant located at Chidambaram Municipality, Chidambaram, and fed to the reactor with 780 mg/L COD with an organic loading rate of 0.123 kg COD/m^3 d. In order to successfully start the functioning of AMBR, the initial loading rate was suggested. It is important to have an appropriate start-up for

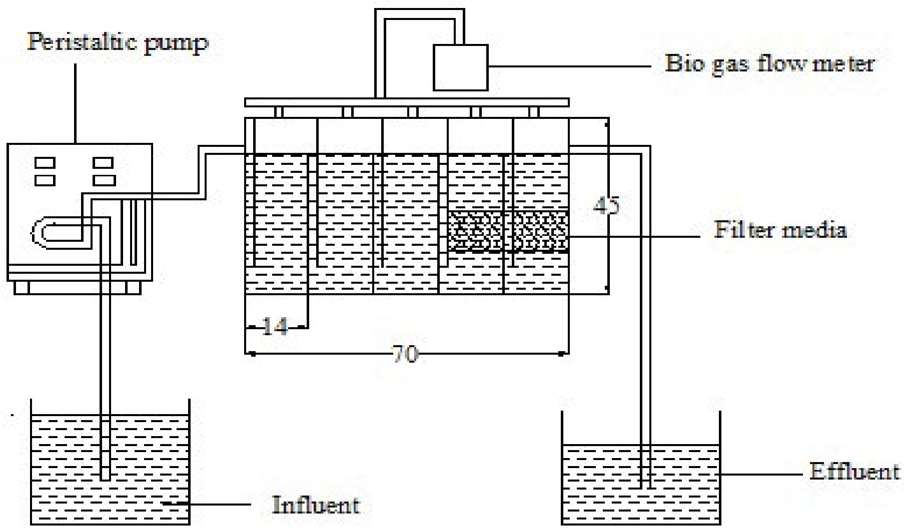

Fig. 1. Schematic diagram of an experimental setup.

Fig. 2. Photographic view of bio carriers.

Table 1
Physical features and process parameters of experimental model

Reactor configurations	Dimensions
Length of the reactor	70 cm
Depth of the reactor	45 cm
Width of the reactor	25 cm
Compartment free board	6 cm top
Total volume of the reactor	78.75 L
Working Volume	68.25 L
Number of compartment	5
Each compartment length	14 cm
Peristaltic pump	PP-30

Table 2
Characteristics of realtime institutional wastewater

Sl. No.	Parameters	Sample (S1)	Sample (S2)	Sample (S3)	Desirable limit of IS 10500
1	pH	6.4	6.8	6.6	6.5–8.5
2	Total solids, mg/L	5,200	6,200	5,800	500
3	Total suspended solids, mg/L	3,500	4,100	3,900	100
4	Total dissolved solids, mg/L	1,700	2,100	1,900	500
5	Oil and grease, mg/L	0.0403			10
6	BOD5 at 20°C, mg/L	380	406	376	30
7	COD, mg/L	760	840	784	250
8	Ammonical nitrogen, mg/L	7.30	8.60	8.40	50
9	Chlorides, mg/L	140	240	160	250
10	Turbidity (NTU), mg/L	9.80	10.60	9.50	5
11	Temperature, °C	28	29	28	<40
12	Sulphates, mg/L	2,250	2,050	2,180	200
13	Phosphate, mg/L	68.8	72.8	85	NA
14	Hardness, mg/L	1,800	1,900	1,750	200
15	Sodium, mg/L	2,833	2,900	2,710	200
16	Potassium, mg/L	13.50	26.85	24.90	NA
17	Calcium, mg/L	69.50	53.20	61.80	75
18	Lithium, mg/L	5.30	6.50	5.80	2.5

the AMBR to function efficiently. This is because of the slow growth rates of the anaerobic microbes, especially those bacteria that produce methane.

3.2. Start-up of the reactor

The COD removal efficiency during start-up was incremental up to 12 d whereas from 12th to 15th day, the removal efficiency got decreased which might be due to the accumulation of VFA production in the reactor. From 15th day onwards, the removal efficiency got increased and attained steady-state from 18th to 21st day. In the earlier research work that had done by the author (ABR without bifurcation), the steady-state was attained in the timeline that spanned between 75 and 78 d [27]. The bifurcation of the acetogens and methanogens are essential to separate the acetogenic and methanogenic microorganisms and to retard the growth of acetogenic microorganisms by overwhelming the growth of methanogenic microorganisms. By bifurcating the acetogens and methanogens, the process efficiency can be improved. Fig. 3 shows the influent COD and effluent COD whereas Fig. 4 shows the COD removal efficiency during the start-up of the reactor. The impact of pH upon the influent and effluent in the reactor is shown in Fig. 5. The biogas produced in the reactor was very minimum which might be due to the low strength of the wastewater being 0.001 to 0.0014 m^3 of biogas per kg COD removed and is shown in Fig. 6. As to improve the biogas yield and the removal efficiency, co-substrate can be added with the support of literatures.

Once the steady-state was attained, the reactor was permitted to function with institutional wastewater under eight hydraulic retention times (HRT) of 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 5.0, and 6.0 d in addition to three average influent CODs of 876, 764, and 660 mg/L. The COD is used as a measure of the oxygen equivalent of the organic content of a sample that undergoes oxidation with the influence a strong chemical agent. The samples were refluxed in a strong acid solution with a known excess of potassium dichromate. A standard 2 h reflux time was used. The

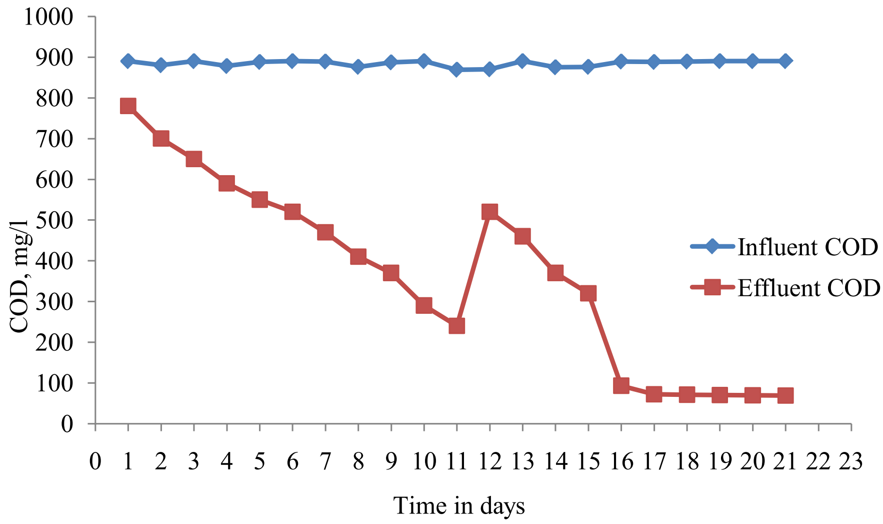

Fig. 3. Time in days vs. influent COD and effluent COD during start-up process.

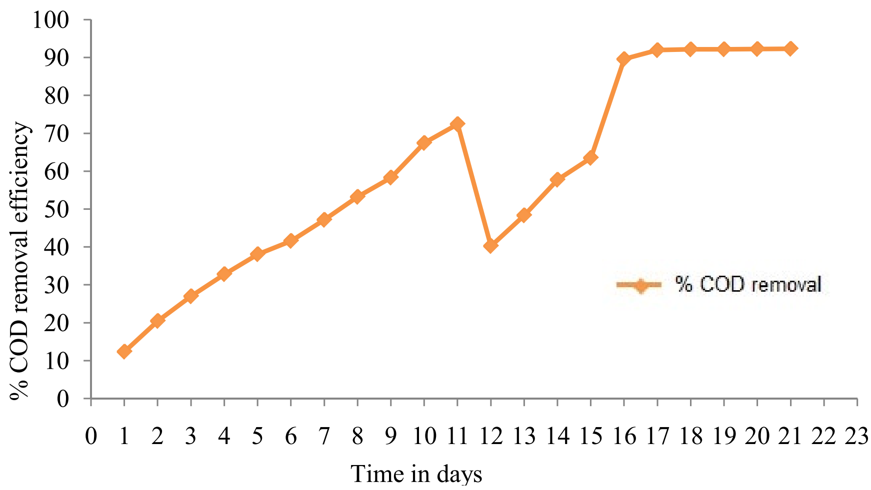

Fig. 4. Time in days vs. % COD removal efficiency during start-up process.

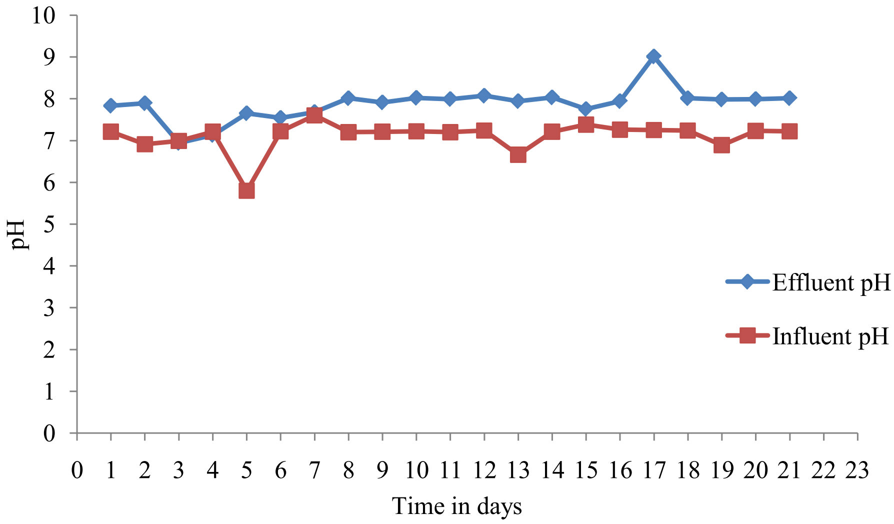

Fig. 5. Time in days with respect to influent and effluent pH during start-up process.

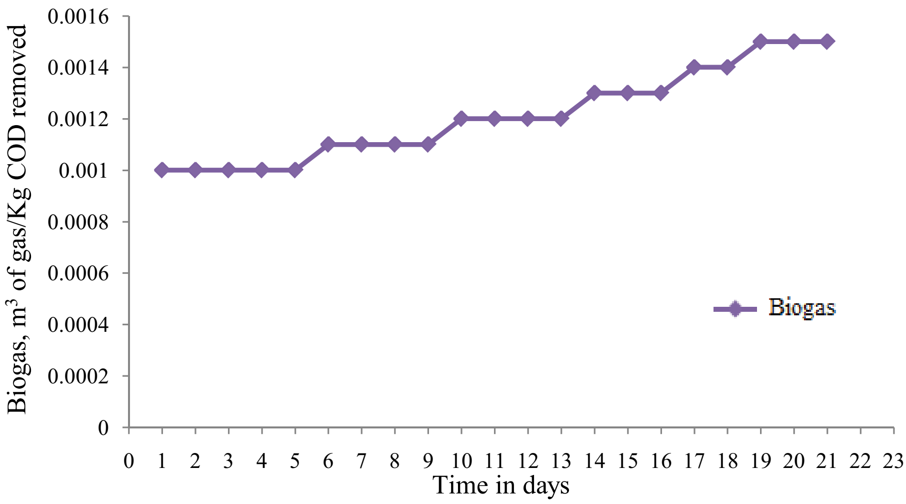

Fig. 6. Time in days with respect to biogas, m^3 of gas/kg COD removed during start-up process.

oxygen equivalent was considered for the calculation of the oxidizable organic matter, after the digestion process which involved the remaining unreduced $K_2Cr_2O_7$ for titration with ferrous ammonium sulfate in order to determine the amount of $K_2Cr_2O_7$ consumed. The oxidizable organic matter was calculated in terms of the oxygen equivalent. This organic loading was a real-time influent without the addition of any co-digestion. The pH of each compartment was recorded with respect to HRT. In this experiment, VFA and pH are the key parameters that affect both the treatment efficiency as well as the microbial community during the anaerobic digestion process. Figs. 7–9 are graphical representations of pH range in each compartment under the operational conditions of HRT for average COD values of 876, 764, and 660 mg/L. The first compartment underwent hydrolysis and the pH was from 6.02 to 6.41 during the experimental period. There was a sudden drop (from 5.2 to 5.9) in the pH experienced in the second compartment. This might be due to the growth of acidogenic population. The pH of the third compartment got slightly increased from 5.80 to 6.39 and it further increased in the fourth compartment from 6.66 to 7.25. In the fifth compartment, the pH was in the range of 7.49 and 8.49 due to the effective degradation of VFA. The relatively low pH values from the second compartment indicated that the wastewater was fermented to VFA by acetogens. The methodology for VFA is to add 200 mL of samples into COD digestion flask and add 4 mL of H_2SO_4. Then connect the inclined condenser jar and allow water to flow. Heat the condenser at 80°C and collect the condensate. Pour the first 15 mL and then collect the next 150 mL. Switch off the heater and take 150 mL condensate in a conical flask. Take a burette and fill it with 0.1 N of NaOH. Add 3 drops of phenopthaline indicator and titrate with NaOH. Appearance of pink color indicates the end point. CO_2 was quantified by using the biogas flow meter.

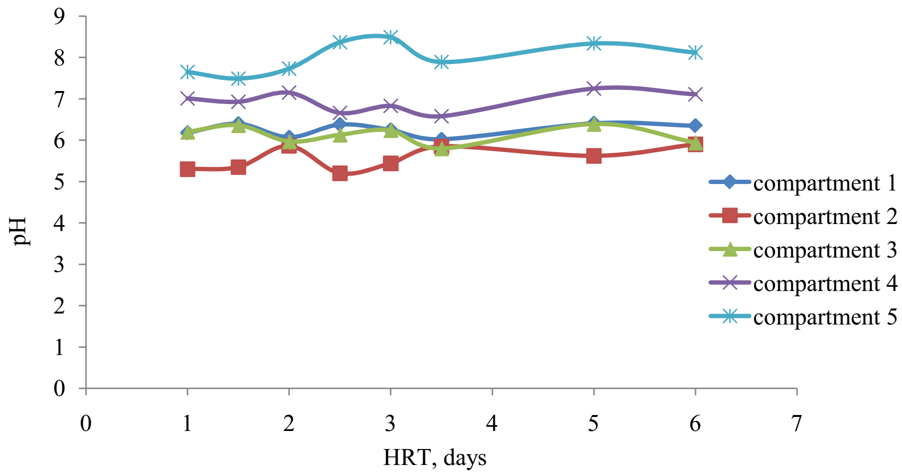

Fig. 7. HRT in days with respect to pH with an average influent COD of 876 mg/L.

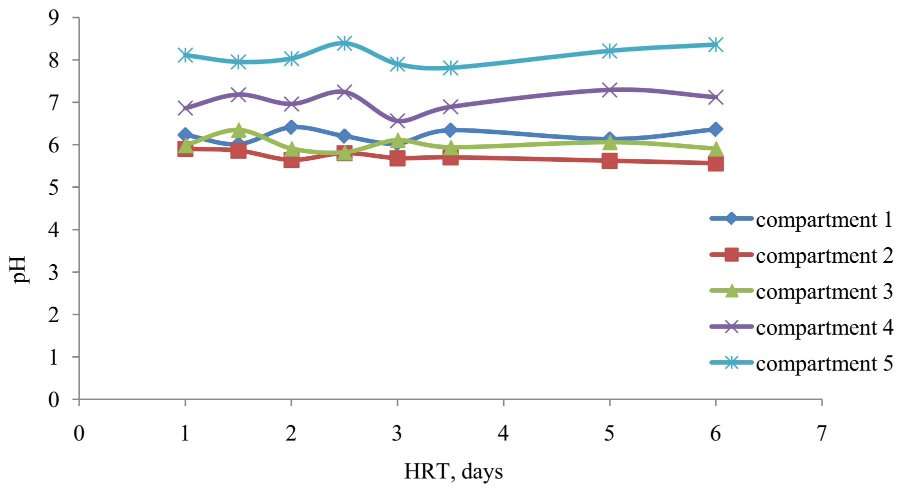

Fig. 8. HRT in days with respect to pH with an average influent COD of 764 mg/L.

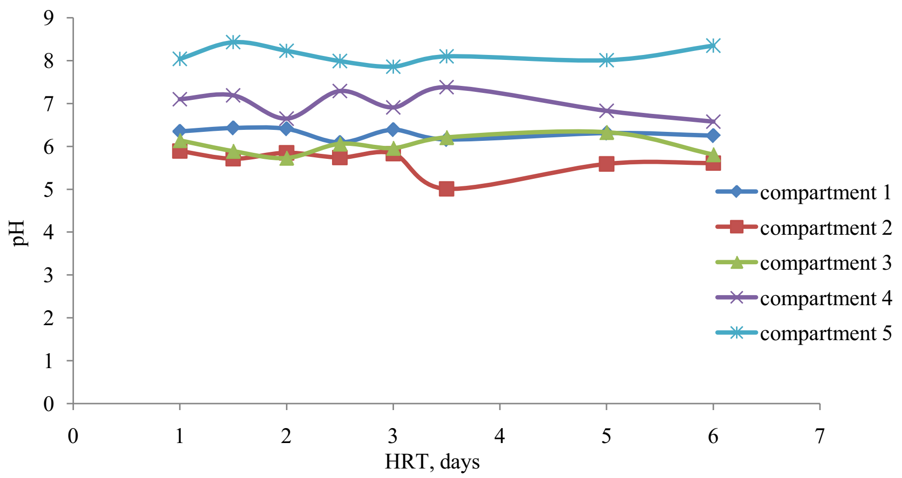

Fig. 9. HRT in days with respect to pH with an average influent COD of 660 mg/L.

The influence in the first compartment got hydrolyzed to simple organics. This result demonstrates that the VFA got converted to acetate and hydrogen gas by acetogens in second and third compartments. Furthermore, these intermediates were then encouraged to be converted as methane by methanogens in the subsequent compartments (4 and 5). The behavior of the pH concentration confirmed that the hydrolysis and acidogenesis remain the most critical biochemical activities that occurred in the first two compartments while methanogenesis dominated in the last two compartments.

But the quick changes that occur in parameters such as temperature, hydraulic or organic overloading, and the availability of inhibitory substances may change the stability of the digester [28]. In such a scenario, the VFA gets accumulated thus destabilizing the digester. This creates a situation in which the proton overflow occurs and the bicarbonates in the liquid phase get decomposed to produce CO_2. This production of carbon dioxide increases its fraction in the gas phase and reduces the pH of the digester drastically [29]. The current research work investigated the effect on bifurcation of acidogenic (*Escherichia coli*) and methanogenic microorganism (*Lactobacillus*) in a compartmentalized AMBR [24]. In this reactor, the biomass is migrated through the baffles which help to stimulate the decomposition of organic matters. The pH drop was noted down in the first two compartments which then saw a steep increase in the subsequent compartments with average CODs being 876, 764, and 660 mg/L (Figs. 7–9). The pH drop was counterbalanced and buffered with the formation of the alkaline conditions in CO_2 production. The incorporation of attached and the suspended growth system in a single compartmental AMBR as a novel technology supports the reduction of start-up period and helps in increasing the removal efficiency. The COD removal efficiency in the suspended growth system for an average influent COD of 888 mg/L in the third compartment was 30.35%. Similarly, for an average influent COD of 764 and 660 mg/L was 35.35% and 71.26%, respectively. Whereas in the fourth and fifth compartment with the attached growth process for an average influent COD of 888, 764, and 660 mg/L was 51.588%, 60.17%; 68.68%, 71.71%; and 75.86%, 77.01%, respectively. Hence, it is necessary to use the bio carriers with the attached growth process.

4. Conclusions

The pH variations during anaerobic digestion in each compartment of the AMBR during the treatment of institutional wastewater were recognized. The methanogenic community for metabolism was hampered due to the lower level of pH in the first two compartments viz 6.7 and 5.9. The incremental range of pH in the fourth and fifth compartments indicated that the metabolism process was in a methanogenic state. The minimum pH of 5.01 in the second compartment and maximum pH in the fifth compartment of 8.49 with an influent at 3 d HRT was identified. The VFA concentration was higher due to the acid accumulation in the reactor and dampens pH level that inhibits the hydrolysis and acidogenic phase. Since the pH was low (6.7 and 5.9) in the first two compartments, the methanogenic community for metabolism got hampered. The 4th and 5th compartments that had high pH values conclude that the metabolism process was in a methanogenic state. The 5th compartment had a high pH value, that is, 8.49 with 872 mg/L influent COD at 3 d of HRT. The study analyzed the impact of pH in the growth of acidogenic and methanogenic organisms with respect to the reduction of organic substance. Since the acid got accumulated in the reactor, the VFA concentration got increased which in turn reduced the pH level eventually preventing the hydrolysis and acidogenic phase in the 1st and 2nd compartments. In this study, the hydraulic shock loads, due to the accumulation of VFA, were not identified due to the bifurcation of acetogens and methanogens.

Acknowledgments

The author and her co-workers are grateful for the financial support from the Science Engineering Research Board, Department of Science and Technology, New Delhi. Also, thank to the authorities of Annamalai University.

References

[1] E. Garcıa-Quismondo, C. Santos, J. Palma, M.A. Anderson, On the challenge of developing wastewater treatment processes: capacitive deionization, Desal. Water Treat., 57 (2016) 2315–2324.
[2] R. Rautenbach, K. Vossenkaul, T. Linn, T. Katz, Wastewater treatment by membrane process – new development in ultrafiltration, nanofiltration and reverse osmosis, Desalination, 108 (1997) 247–253.
[3] A. Bachmann, V.L. Beard, P.L. McCarty, Comparison of fixed film reactors with a modified sludge blanket reactor: fixed film biological processes for wastewater treatment, Water Res., 18 (1983) 50–58.
[4] S. Wanasen, Upgrading Conventional Septic Tanks by Integrating In-Tank Baffles, Thesis, EV-03–20, Asian Institute of Technology (AIT), Bangkok, 2003.
[5] A.A.M. Langenhoff, D.C. Stuckey, Treatment of dilute wastewater using an anaerobic baffled reactor: effect of low temperature, Water Res., 34 (2000) 3867–3875.
[6] R. Boopathy, V.F. Larsen, E. Senior, Performance of anaerobic baffled reactor (ABR) in treating distillery wastewater from a scotch whisky factory, Biomass, 16 (1988) 133–143.
[7] A. Grobicki, D.C. Stuckey, Performance of the anaerobic baffled reactor under steady-state and shock loading condition, Biotechnol. Bioeng., 37 (1991) 344–355.
[8] T. Setiadi, Husaini, A. Djajadiningrat, Palm oil mill effluent treatment by anaerobic baffled reactor: recycle effect and biokinetic parameters, Water Sci. Technol., 34 (1996) 59–66.
[9] A. Bhuvaneswari, B. Asha, Effect of HRT on the biodegradability of textile wastewater in an anaerobic baffled reactor, Int. J. Sci. Eng. Res., 6 (2015) 1457–1460.
[10] W.P. Barber, D.C. Stukey, The use of the anaerobic baffled reactor (ABR) for wastewater treatment: a review, Water Res., 33 (1999) 1559–1578.
[11] R. Boopathy, Biological treatment of swine waste using anaerobic baffled reactor (ABR), Bioresour. Technol., 64 (1998) 1–6.
[12] L.T. Angenent, G.C. Banik, S. Sung, Psychrophilic anaerobic pretreatment of low-strength wastewater using the anaerobic migrating blanket reactor, Proc. Water Environ. Fed., 2000 (2000) 746–763.
[13] J. Plumb, J. Bell, D.C. Stuckey, Microbial populations associated with treatment of an industrial dye effluent in an anaerobic baffled reactor, Appl. Environ. Microbiol., 67 (2001) 3226–3235.
[14] S. Uyanik, P.J. Sallis, G.K. Anderson, The effect of polymer addition on granulation in an anaerobic baffled reactor (ABR). Part 1: process performance, Water Res., 36 (2002a) 933–943.

[15] A. Bach Bachman, V.L. Beard, P.L. McCarty, Performance characteristics of the anaerobic baffled reactor, Water Res., 19 (1985) 99–106.
[16] K.M. Foxon, S. Pillay, T. Lalbahadur, N. Rodda, F. Holder, C.A. Buckley, The anaerobic baffled reactor (ABR), an appropriate technology for on-site sanitation, Water SA, 30 (2007) 44–50.
[17] I.D. Manariotis, S.G. Grigoropoulos, Low-strength wastewater treatment using an anaerobic baffled reactor, Water Environ. Res., 74 (2002) 170–176.
[18] S.R. Hassan, I. Dahlan, Anaerobic wastewater treatment using anaerobic baffled bioreactor: a review, Cent. Eur. J. Eng., 3 (2013) 389–399.
[19] S.Y. Bodkhe, A modified anaerobic baffled reactor for municipal wastewater treatment, J. Environ. Manage., 90 (2009) 2488–2493.
[20] Y.-K. Gong, H.-Q. Xiang, L. Mu, Study on performance of anaerobic baffled reactor treating wastewater from penicillin production, Mod. Chem. Ind., 26 (2006) 172–175.
[21] L.T. Angenent, G.C. Banik, S. Sung, Anaerobic migrating blanket reactor treatment of low-strength wastewater at low temperatures, Water Environ. Res., 73 (2016) 567–574.
[22] M. Ghasemian, E. Taheri, A. Fatehizadeh, M.M. Amin, Biological hydrogen production from synthetic wastewater by an anaerobic migrating blanket reactor: artificial neural network (ANN) modeling, Environ. Health Eng. Manage. J., 6 (2019) 269–276.
[23] L.T. Angenent, S. Sung, Development of anaerobic migrating blanket reactor (AMBR), a novel anaerobic treatment system, Water Res., 35 (2001) 1739–1747.
[24] C. Aruna, B. Asha, The effect on bifurcation of acidogenic and methanogenic microorganism in a compartmentalized anaerobic migrating blanket reactor, J. Eng. Adv. Technol., 8 (2019) 92–95.
[25] G. Hayder, L. Guan, Evaluation of bio-carrier in attached growth wastewater treatment system, J. Adv. Res. Fluid Mech. Therm. Sci., 19 (2016) 10–14.
[26] American Public Health Association, American Water Works Association, Water Environment Federation, Standard Methods for the Examination of Water and Wastewater, 23rd ed., Washington, DC, 2017.
[27] A. Bhuvaneswari, B. Asha, T. Saranya, Start-up and enhancement of granulation in an anaerobic baffled reactor for the treatment of textile wastewater, Int. Acad. Sci. Eng. Technol., 4 (2015) 11–16.
[28] Y. Chen, J.J. Cheng, K.S. Creamer, Inhibition of anaerobic digestion process, a review, Bioresour. Technol., 99 (2007) 4044–4064.
[29] W.E. Ripley, J.C. Boyle, Converse Alkalinity Considerations with Respect to Anaerobic Digester, Proceedings 40th Industrial Waste Conference, Purdue University, EUA, Boston, MA, 1985.