4thInternational Conference on Advances in Civil Engineering 2018 (ICACE 2018)
19 –21 December 2018
CUET, Chittagong, Bangladesh
www.cuet.ac.bd

EFFECT OF LOW TEMPERATURE ON HYDRODYNAMICS OF A HYBRID ANAEROBIC BAFFLED REACTOR (HABR)

R. Haque[1*], M. Khalekuzzaman[1], M. Hasan[1], K. Islam[2]& F. Rabbi[1]

[1]Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna.
Email: shimul2k13@gmail.com; kzaman@ce.kuet.ac.bd
[3]WaterAid Bangladesh, Email: khairulislam@wateraid.org
**Corresponding Author*

ABSTRACT

This paper presents a study on the effect of low temperature on hydrodynamics of a hybrid anaerobic baffled reactor (HABR) with seven compartments, in which first five were anaerobic baffled reactor and the rest two were floated/fluidized bed reactor. The reactor was run with a constant hydraulic retention time (HRT) of 10 h at 25°C (normal water) and 10°C (cold water). Residence time distribution studies were carried out by tracer experiment to evaluate the hydrodynamic flow characteristics under variable temperature. The mean residence time of the reactor at 25°C was found 4.77% greater than the other temperature. No significant difference in mixing pattern was observed after the first chamber due to temperature change. However, it was observed that the dispersion number (1/Pez) is 57% higher in the first chamber in case of normal water than cold water. Dead space from 1st to 5th chamber was changed due to temperature change. Dead space in the 5th chamber at 10°C was found 80% higher than 25°C. As dead space was 0 in the 6th chamber for the two temperatures; therefore, the optimal number of chamber of the reactor should be 6 for both temperatures. A very good hydraulic efficiency ($\lambda p \geq 0.75$) was obtained from 4th to effluent for the two different temperatures.

Keywords: anaerobic baffled reactor; hydrodynamics; temperature; residence time distribution; tracer.

1. INTRODUCTION

Nowadays, a lot of completely controlled reactors have been used for treating wastewater. Over the last 20 years, it has been observed that significant advances have been made in anaerobic reactor design (Speece, 1996). These advances have allowed reactors to have a high solids retention time (SRT 20±100 days) while maintaining the hydraulic retention time (HRT) to a minimum (1.3±20 h), and have enabled economic treatment of a variety of dilute wastes, like sewage (Langenhoff, 2000a). Among of them a novel type of reactor is the Anaerobic Baffled Reactor (ABR). Initially, McCarty and his co-workers developed the anaerobic baffled reactor at Stanford University to treat high strength wastewater (McCarty, 1982). ABR basically represents an arrangement of a series of the up-flow anaerobic sludge blanket (UASB) reactors. There is an arrangement of vertical baffles that guide the wastewater to flow under and over them (Barber & Stuckey, 1999). Anaerobic digestion technology has some advantages, like larger biomass retention, proper system stability, needs no aeration, and high COD removal efficiency (Chen et al., 2011; Demirel, Yenigun, & Onay, 2005; Lu, Ma, Liu, & Li, 2011). Now the treatment efficiency of an anaerobic digestion process primarily depends on two important factors: reactor's hydrodynamics and the performance of the microbiological processes which are predominantly influenced by its construction (Ascuntar Rios et al.,2009)

Hydrodynamics and Hydraulics of flow are among the crucial factors in the design and operation of various wastewater treatment technology. The efficiency of wastewater treatment processes in any biological reactor largely depends on the hydrodynamic behaviour of that reactor. The extent of contact between the substrate and bacteria is greatly influenced by the degree of mixing that occurs within a biological reactor, thus controlling mass transfer (Mansouri et al., 2012). Therefore, hydrodynamic characteristic is an important factor for good reactor configuration.

The efficient treatment of low strength wastewaters in an anaerobic baffled reactor (ABR) at mesophilic temperature (at low retention times) has been described elsewhere (Langenhoff, 2000a). Almost every full-scale treatment systems work below the mesophilic temperatures (30±35°C). However, the temperature a huge amount of wastewaters, including domestic sewage, is lower than 35°C, heating is required and which increases the costs of treatment. Therefore, if anaerobic treatment systems able to treat wastewater at low temperatures (10±2°C) it will reduce the treatment costs for low-temperature wastewaters, and could significantly enhance the range of anaerobic treatment (Langenhoff, 2000b). The performance of an anaerobic reactor can be affected by the Reduction of the operating temperature as biological processes are affected by temperature (Nachaiyasit & Stuckey, 1997). So it is clear that temperature has a significant effect on the first factor (performance of the microbiological processes) on which the treatment efficiency of a reactor depends. But the effect of temperature on the hydrodynamics of an anaerobic baffled reactor which is the second crucial factor is not clear yet.

2. METHODOLOGY

2.1. Reactor Configuration

The hybrid anaerobic baffled reactor, which is a type of ABR with two fluidized bed reactor can be used to treat high strength wastewater. A laboratory scale anaerobic baffled reactor with seven compartments, first five are anaerobic baffled reactor and rest two are fluidized bed reactor was developed. The walls and baffles are constructed with clear acrylic plastic (celluloid sheets). The reactor is rectangular in shape. The total volume of the reactor was 38.6L and has a length of 90 cm, width of 20cm and a height of 30cm. The 7 compartments are separated by standing baffles. There are also hanging and inclined baffles which make the water path zigzag in pattern. As a result, there is an up-flow and down-flow section in a ratio of 4:1 in every compartment. The length of the first chamber was 22cm, second to fifth was 11cm, and last two chamber was 12cm in length. The lower portion of the inclined baffles was bent at 45° to route the flow to the centre of the up-flow chamber, thus achieving better contact and greater mixing of feed and bio-solids. There is a sampling port at each chamber to collect sample. The last two chambers of the baffled reactor were packed with Shredder plastic bottle cork worked as fluidized bed reactor. The main advantages of this type of filter media are that it has a lower specific gravity than water. So it floats above water and does not block the water way. A dispensing pump was used to flow water into the reactor. Temperature of effluent water was controlled by water bath (Nuve BM30) up to ±2°C.

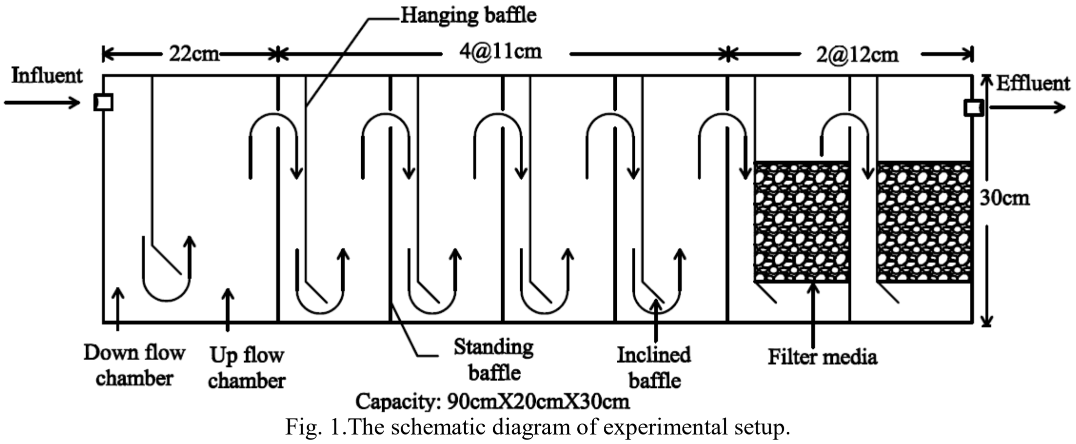

Fig. 1.The schematic diagram of experimental setup.

2.2. Experiment method

Tap water of 25°C (normal water) and 10°C (cold water) was used as influent at a constant HRT (10HRT). Residence time distribution (RTD) studies were performed to analyse the hydrodynamics of the reactor by injecting an inert tracer to the reactor by pulse input method and response was observed thus, the RTD curve was plotted. Tracer was injected instantaneously before the inlet at the very beginning of the run. The effluent samples were taken from the sampling port of the reactor at regular intervals from the time of impulse and the total sampling time was 2.5 times of nominal HRT. The EC of the samples were measured. From the measured EC concentration of tracer was calculated.

2.3. Theoretical Interpretation

The normalized RTD curve is developed in terms of normalized time against normalized tracer concentration

$$\text{Normalized time}, \theta = \frac{\text{time(h)}}{\text{HRT(h)}} \qquad (1)$$

$$Normalized\ concentration, \mathrm{C}\theta = \frac{C(t)\ concentration(mg/L)}{\mathrm{Co}\ nitial\ concentration(mg/L)} \qquad (2)$$

Where C_{Θ} is the normalized tracer concentration at dimensionless time Θ. The tracer concentration at time t is C(t) and the initial tracer concentration is C_0 (Grobicki & Stuckey, 1992b).

Equation [1] and [2] provide the expressions of normalized concentration (C_{Θ}) as the vertical-axis and normalized time (Θ) as the horizontal-axis for comparisons between the RTD studies.

The normalized curve is also called RTD curve, and when tracer is used by a pulse input method, the area covered by the normalized curve is known as E curve (exit age curve), that is the time take for the fluid to come out of the outlet. The area under the E curve is equal to 1.

$$\int_{\mathbf{0}}^{\boldsymbol{\alpha}} E(t)dt = 1$$

Here E(t) is the RTD function. The RTD function, E(t), value is correlated to the C(t) value as shown in Eq. (4) & (5), which was used to calculate E(t), the mean residence time τ and σ^2 variance of RTD studies (Renuka et al., 2015).

$$E(t) = \frac{c(t)}{\int_0^{\infty} \mathrm{c(t)dt}} \qquad (3)$$

$$\tau = \frac{\int_0^{\infty} \mathrm{tE(t)dt}}{\int_0^{\infty} \mathrm{E(t)dt}} = \int_0^{\infty} \mathrm{tE(t)dt} \qquad (4)$$

$$\sigma^2 = \int_0^{\infty} (t-\tau)^2 E(t)dt \qquad (5)$$

Dead space could be calculated as:

$$X = \left(1 - \frac{\tau}{HRT}\right) * 100 \qquad (6)$$

Dispersion model: $$\sigma_{\theta}^2 = 2\left(\frac{D}{uL}\right) - 2\left(\frac{D}{uL}\right)^2 \left(1 - e^{-uL/D}\right) \qquad (7)$$

Where, N = number of theoretical tanks in series, D = molecular diffusivity (cm2/s), u = average liquid velocity (cm/s), L= liquid path length through reactor (cm). If D/uL = 0, the reactor approximated to the ideal plug-flow reactor (PFR, D/uL= 0). If D/uL =∞, the reactor approximated to the ideal continuous-flow stirred-tank reactor (CSTR, D/uL= 1). In case of non-ideal flow, D/uL value was between 0 and 1

(0 < D/uL< 1) (Xu, Ding, Xu, Geng, & Ren, 2014). N, the main parameter of the Tank in series model, could be calculated by Eq. 8. The tank-in-series (TIS) model simulates the number of actual CSTR reactor (with the same volume) in series. If N → 1, the reactor represented as a CSTR, and if N→∞, the reactor represented to plug flow reactor (PFR) (Renuka et al., 2015).

$$\mathrm{N} = \frac{1}{\sigma_\theta^2} \qquad (8)$$

The hydraulic efficiency represents the ability of the system to distribute its flow uniformly throughout its volume, maximizing the contact time of pollutant in the system and optimizing the ability to break down the pollutants (Renuka et al., 2015). The value range of hydraulic efficiency varies from 0 to 1, and classified into three groups: (1) good hydraulic efficiency with $\lambda > 0.75$, (2) satisfactory hydraulic efficiency $0.5 < \lambda \leq 0.75$ and (3) poor hydraulic efficiency $\lambda \leq 0.5$.

$$\lambda = e\left(1 - \frac{1}{N}\right) \qquad (9)$$

Where, e is the effective volume, calculated as one minus dead space and N is the number of on continuous stirred tanks in series(Sarathai, Koottatep, & Morel, 2010).

RESULTS AND DISCUSSIONS

RTD of ABR

The RTD curves for the two different temperatures 25^0C and 10^0C obtained by plotting normalized time vs. concentration (mg/L). Fig. 2(a) shows the RTD of 1-, 2-, 3-, 4-, 5-, 6-, 7-chamber and effluent of the HABR at 25^0C and Fig. 2(b) at 10^0Crespectively. As shown in the figures, the reactor residence time curve firstly rises and then drops, forming one single peak. With the increase in the ABR chambers, the peak value of the RTD curves decreased as well, while the distribution width of the RTD curves turned wider on the time axis for both temperatures.

(a)

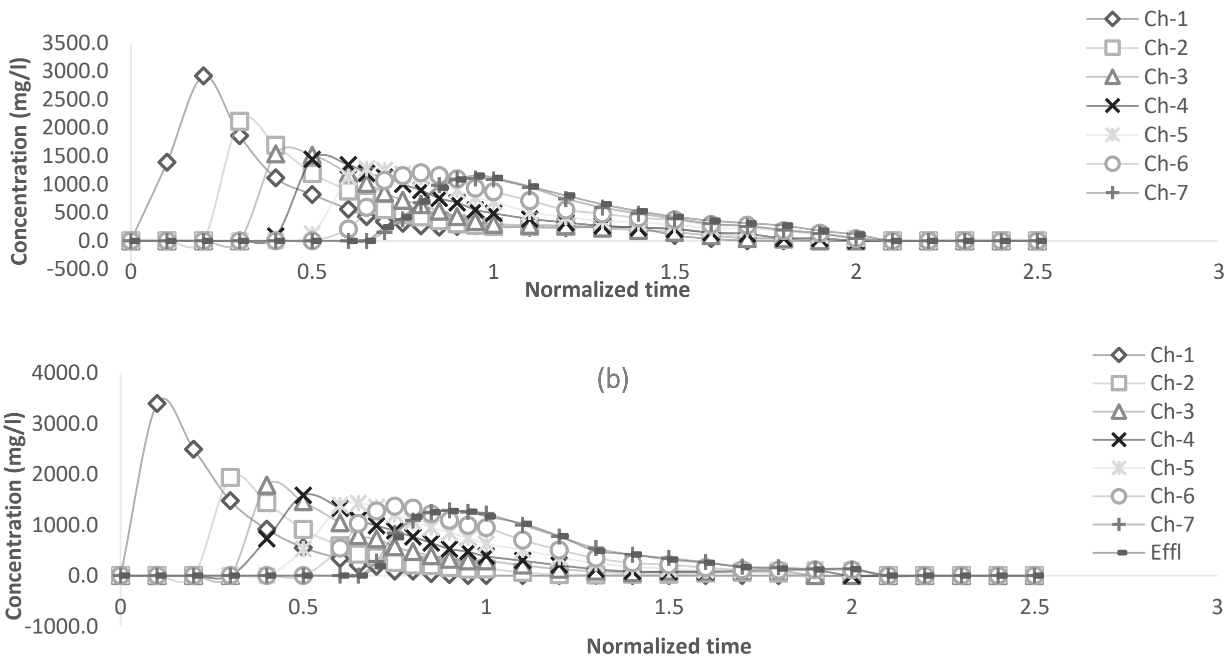

Fig. 2.RTD curves of HABR for normal water (a). RTD curves of HABR for cold water (b)

Mean Residence Time

The analysis of the RTD for the two different temperatures showed that, with the increase in the ABR chambers, the mean residence time also increase. The mean residence time for 25°C was found 4.8% greater than 10°C. The mean residence time was obtained at chamber-6 for normal water and chamber-7 for cold water. That's mean the atoms leave the reactor to spend enough time Fig. 3(a).

Mixing pattern

The term ul/D is called peclet number (Pez). It was found that 1/Pez of normal water is 57% higher than cold water but after first chamber temperature had no significant effect on mixing pattern. As the value of D/ul moved to 0 with the increase of number of chamber, the fluid in the reactor increasingly took the form of plug flow Fig 3(b).

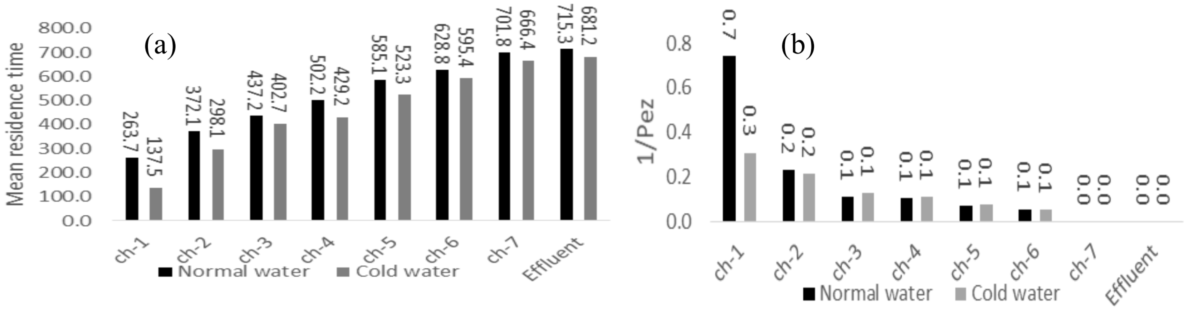

Fig .3. Mean residence time of various chambers & effluent at 25^0C and 10^0C (a). 1/Pez of chambers and effluent of the ABR at 25^0C and 10^0C (b).

Dead Space

Dead space in the reactor generally represents the hydraulic dead space and biomass dead space. But in this study, tap water was used to analyse the hydrodynamic characteristics so dead space represent only the hydraulic dead space. As shown in Fig. 4(a) temperature had effect on dead space till 5th chamber. Dead space in 5th chamber at 10°C was found 80% higher than 25°C.But dead space was found 0 in 6th chamber for all the three temperature. Therefore, the optimal number of chamber of the reactor shall be 6 for all the three temperature.

Hydraulic Efficiency

Fig. 4(b) shows that in first two chamber the hydraulic efficiency is poor for normal and cold water. The hydraulic efficiency in the third chamber is satisfactory. But for the 4th to 7th chamber and effluent, hydraulic efficiency was very good as the values of λp were greater than 0.75. As the hydraulic efficiency characteristic was more or less same at each chamber for both temperatures, it is independent of temperature.

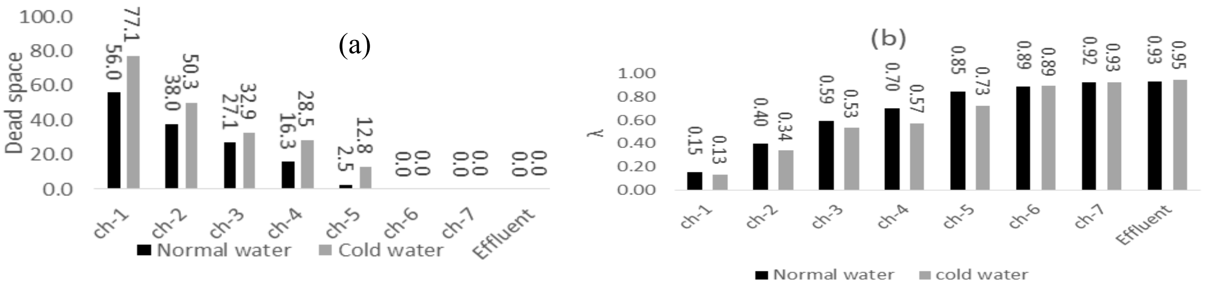

Fig .4. Percentages of dead space in chambers and effluent of the ABR at two different temperatures (a). Hydraulic efficiency in chambers and effluent of the ABR at two different temperatures (b).

CONCLUSIONS

From the RTD analysis it has been shown that temperature has some effect on hydrodynamics of a HABR. Mean residence time of the reactor at 25°C was found 4.7% greater than 10°C. Dead space showed different behaviour at different temperature till 5th chamber. In 5th chamber dead space at 10°C was found 80% higher than 25°C. But it was found 0 in 6th chamber for both temperatures. Therefore, the optimal number of chamber of the reactor shall be 6 for the two temperatures. No significant effect of temperature on mixing pattern and hydraulic efficiency was observed. A very good hydraulic efficiency ($\lambda p \geq 0.75$) was obtained from 4th to effluent for both temperatures. This paper clearly demonstrates a qualitative and quantitative relationship between temperature change and hydrodynamic of a HABR.

REFERENCES

Ascuntar-Rios, D., Toro, A., Peña, M., & Madera, C. (2009). *Changes of flow patterns in a horizontal subsurface flow constructed wetland treating domestic wastewater in tropical regions* (Vol. 35).

Barber, W. P., & Stuckey, D. C. (1999). The use of the anaerobic baffled reactor (ABR) for wastewater treatment: a review. *Water Research*, *33*(7), 1559–1578.

Chen, X., Ping, Z., Ding, S., Tang, C., Cai, J., Lu, H., & Qaisar, M. (2011). Specific energy dissipation rate for super-high-rate anaerobic bioreactor. *Journal of Chemical Technology and Biotechnology*, *86*(5), 749–756.

Demirel, B., Yenigun, O., & Onay, T. T. (2005). Anaerobic treatment of dairy wastewaters: a review. *Process Biochemistry*, *40*(8), 2583–2595.

Grobicki, A., & Stuckey, D. C. (1992). Hydrodynamic characteristics of the anaerobic baffled reactor. *Water Research*, *26*(3), 371–378.

Langenhoff, A. (2000a). Treatment of dilute soluble and colloidal wastewater using an anaerobic baffled reactor: influence of hydraulic retention time. *Water Research*, *34*(4), 1307–1317.

Langenhoff, A. (2000b). Treatment of dilute wastewater using an anaerobic baffled reactor: effect of low temperature. *Water Research*, *34*(15), 3867–3875.

Li, S., Nan, J., Li, H., & Yao, M. (2015). Comparative analyses of hydraulic characteristics between the different structures of two anaerobic baffled reactors (ABRs). *Ecological Engineering*, *82*, 138–144.

Lu, J., Ma, Y., Liu, Y., & Li, M. (2011). Treatment of hypersaline wastewater by a combined neutralization–precipitation with ABR-SBR technique. *Desalination*, *277*(1–3), 321–324.

Mansouri, Y., Zinatizadeh, A. A., Mohammadi, P., Irandoust, M., Akhbari, A., & Davoodi, R. (2012). Hydraulic characteristics analysis of an anaerobic rotatory biological contactor (AnRBC) using tracer experiments and response surface methodology (RSM). *Korean Journal of Chemical Engineering*, *29*(7), 891–902.

McCarty, P. L. (1982). One hundred years of anaerobic treatment. *Anaerobic Digestion 1981. Proc. Symposium, Travemunde*, 3–22.

Nachaiyasit, S., & Stuckey, D. C. (1997). Effect of low temperatures on the performance of an anaerobic baffled reactor (ABR). *Journal of Chemical Technology and Biotechnology*, *69*(2), 276–284.

Renuka, R., Mariraj Mohan, S., & Amal Raj, S. (2015). Hydrodynamic behaviour and its effects on the treatment performance of panelled anaerobic baffle-cum filter reactor. *International Journal of Environmental Science and Technology*, *13*, 307–318.

Sarathai, Y., Koottatep, T., & Morel, A. (2010). Hydraulic characteristics of an anaerobic baffled reactor as onsite wastewater treatment system. *Journal of Environmental Sciences*, *22*(9), 1319–1326.

Speece, R. E. (1996). *Anaerobic biotechnology for industrial wastewaters*. Nashville, Tenn.: Archae Press.

Xu, M., Ding, L., Xu, K., Geng, J., & Ren, H. (2014). Flow patterns and optimization of compartments for the anaerobic baffled reactor. *Desalination and Water Treatment*, 1–8.