CHEMICAL ENGINEERING TRANSACTIONS

VOL. 78, 2020

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-76-1; **ISSN** 2283-9216

DOI: 10.3303/CET2078085

Study on the Performance of Internal Circulation (IC) Anaerobic Digester Treating High Strength of Food Processing Wastewater: Effect of Organic Loading Rate

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Anaerobic digestion (AD) has been known as a feasible process for the conversion of organic waste to biogas. This research aimed to study the performance of an internal circulation (IC) anaerobic reactor treating food processing wastewater under different organic loading rates. The experiment was carried out in a lab-scale of IC reactor at ambient temperature. The reactor was made of poly-methyl methacrylate with dimensions of IC reactor had 1.8 m in height and square surface with 0.12 m in width, the working volume was 25 L. After the acclimation period, the reactor was run for 72 d which was divided into four stages corresponding to four levels of organic loading rate (OLR) as 5; 10; 15 and 20 kg COD m^{-3} d^{-1}. During the experimental period, influent and effluent supernatant was sampled daily and analysed such chemical parameters of pH, TSS (Total suspended solids), COD (Chemical oxygen demand), TN (Total nitrogen), TP (Total phosphorous), biogas volume to evaluate the performance of IC reactor. The result showed that OLR had a significant effect on the removal of organic and nutrient matters in IC reactor. At each level of OLR, the removal efficiency was low at the start and gradually improved to become stable at the end of the phase. IC reactor was good at COD removal and achieved the maximum removal rate 85.4 % at OLR as 10 kg COD m^{-3} d^{-1}. When OLR increased to 15 and 20 kg COD m^{-3} d^{-1}, the reactor could perform stably at maximum COD removal as 84.3 % and 72 %. The maximum biogas production rate was achieved as 93.8 L day^{-1} at day 72^{nd} of the experiment. This study suggests that IC anaerobic reactor is applicable for the removing of organic matter in wastewater at high organic loading rate.

1. Introduction

Aquacultures have been developed in Viet Nam since 1960s. The export aquaculture products have contributed to increase living income for farmers and gross domestic product of Vietnam in recent decades. Many seafood processing factories have been established and operated in Viet Nam to increase the value of aquaculture products for commercial purposes (FAO, 2018). The process of seafood processing includes many steps such as cleaning, disemboweling, cutting and packaging of seafood products (fishes, shells, crabs, and shrimps). Normally, a lot of water is consumed and a large amount of wastewater is generated throughout the process. The wastewater contains many unused parts of seafood such as blood, internal organs, gills, heads, and scales. Therefore, after screening the solid matters, high concentration organics and nutrient compounds is remained in it (Jamieson et al., 2017). Consequently, seafood processing wastewater usually contains high concentration of organic matters and nutrients indicated at high value of BOD_5 (Biochemical oxygen demand), COD, TSS, TN, TP (Gao et al., 2018). The direct ejection of this wastewater to the hydraulic streams may destroy the environment because of eutrophication and pollution. To avoid the negative impacts, many researches have been focused on analyzing characteristics and finding suitable technology for treating seafood processing wastewater (Panpong et al., 2014).

Paper Received: 02/06/2019; Revised: 29/07/2019; Accepted: 25/10/2019
Please cite this article as: Dinh N.T., Luan T.N.B., 2020, Study on the Performance of Internal Circulation (IC) Anaerobic Digester Treating High Strength of Food Processing Wastewater: Effect of Organic Loading Rate, Chemical Engineering Transactions, 78, 505-510 DOI:10.3303/CET2078085

Internal circulation (IC) anaerobic reactor is a feasible technology for the treatment of strength wastewater due to the good performance at the high loading rate, good removal efficiency and low operation cost (Wang et al., 2014). Because of its benefits, IC models have been applied in wastewater treatment and indicated good results. Wang et al. (2014) investigated the performance of a modified IC reactor treating dyeing wastewater and achieved the COD removal efficiency as 87 %, biogas production as 98 L d^{-1}, volatile fatty acids were not accumulated during the experiment. Another study treated landfill leachate by an internal circulation up-flow sludge blanket reactor. The model performed well with high removal of COD (96.49 %) and NH_3-N (99.39 %) at the hydraulic retention time of 12 h (Abood et al., 2013). Until now, there is limited research that refers to the application of IC model in treatment of seafood processing wastewater. It is necessary to investigate the performance of IC model in treatment of different type of wastewater. The output of the research can provide more information about the removal rate and feasible of this model in new contaminants. The aim of the present study was to investigate the performance of IC anaerobic digester treating high strength of seafood processing wastewater.

2. Materials and methods

2.1 Wastewater source and seed sludge

Wastewater was collected from effluents streams of a seafood processing company located in Binh Chanh district, Hochiminh City, Viet Nam. This company mainly produces Tra fish fillet and canned products. The wastewater flowrate is in the range of 300 – 400 $m^3.d^{-1}$. The wastewater was screened to remove particles and stored in the refrigerator at 4 °C before tested. The values of the concentration principal parameters are presented in Table 1.

Table 1: Characteristics of wastewater applied in the experiment

Parameter	Unit	Range
pH	-	6.9 – 7.24
TSS	mg L^{-1}	600 – 986
COD	mg L^{-1}	3,880 – 4,250
TN	mg L^{-1}	39.2 – 65.7
TP	mg L^{-1}	19.3 – 23.6

2.2 Granular sludge forming

In order to accelerate the start-up of the anaerobic process, the reactor was seeded with acclimated anaerobic microorganisms. The seed sludge for inoculating into IC reactor was PVA-gel sludge which was harvested from an anaerobic reactor treating brewery effluent for six months. The total solid concentration of the biomass layer was 0.2 gTS/g PVA gel. Before doing the experiment, 7.5 L of PVA-gel granular sludge was injected to the reactor. After that, the seafood processing wastewater was ten times diluted and filled to the reactor to reach working volume (Dinh et al., 2019). After installing all segments of the reactor, nitrogen gas was purged to the reactor to release oxygen. The effluent was pumped out and recycled continuously within 5 d. The reactor was operated at low organic loading rate until the performance of reactor displace stable and microorganisms were acclimated indicated at stable gas production rate and no sludge washed out. After that, influent metering pumps, biogas meter, and other components were installed and started to operate in the first phase of the experiment.

2.3 Experimental configuration and operation

The research was carried out in a lab-scale of an internal circulation (IC) reactor which was made of poly-methyl methacrylate with the working volume of 25 L. The reactor was divided into three zones: the first compartment contained PVA-gel granules which had diameter of 2-3 mm and the total volume of granules was 7.7 L; The second one contained some slight granular pieces raised from the first zone under hydraulic shear force; the gas-liquid separator area was at the top (Figure 1). Wastewater was distributed to the reactor from the bottom and passed through the sludge bed at the first compartment. A suitable up-flow velocity could keep granular sludge to be suspended in the reactor. The microorganisms mainly convert pollutants under the anaerobic condition to produce biogas in the first compartment. After that, treated wastewater and biogas was passed through the second compartment and separated at the top zone. An inner tube was established at the center of the reactor, the biogas pressure at the top could make a part of influent to go through the tube to the bottom zone for circulating (internal circulation). The reactor was operated for 72 days duration which was included four phases; the OLR of the start-up time was 5 kg COD m-3 d-1 and increased to the next phase after 18 d of operation.

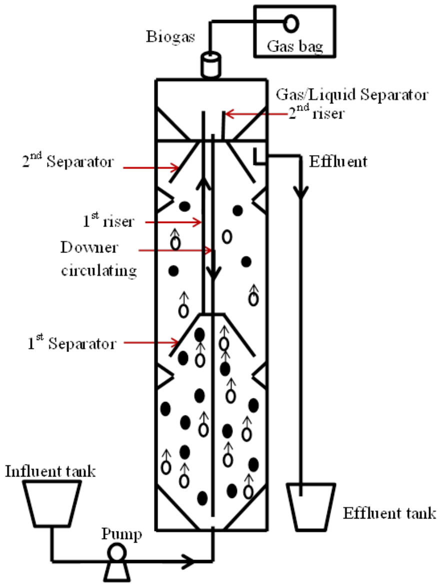

Figure 1: The schematic diagram of the internal circulation reactor

2.4 Sampling and analytical methods

During time course, influent and effluent samples were taken daily and analysed to evaluate the performance of IC reactor. Chemical parameters such as such parameter pH, TSS, COD, TN, TP, were measured in the laboratory. Namely, pH was monitored by pH meter (PH-3P, Mettler Toledo - Tokyo, Japan); Other parameters were analysed by following the instruction in Standard Methods for the Examination of Water and Wastewater, USA in which the detail method for TSS, COD, TN, and TP were 2540 D; 2550 B; 4500 AB; 4500 D (APHA, 2005). The biogas volume was measured daily using a gas meter. Biogas composition was analysed using gas chromatography-mass spectrometry (GC-MS) (Dinh et al., 2014).

3. Results and discussion

3.1 pH and Total suspended solids (TSS) profile

The pH of raw wastewater was in the range of 6.9-7.1. From the previous study pH profiles had trend to drop during first days of the start, therefore, to avoid of decreasing deeply pH values, the pH value of the substrate was adjusted to 7.5 before injecting to the reactor (Dinh at al., 2014). It is clearly that pH was decreased to 6.5-6.8 during the early phase of each loading rate. After that, it was increased and stable at the range of 7.1-7.2. The reduction of pH maybe attributed to the accumulation of volatile fatty acid during the start-up and the change of organic level in the anaerobic digestion process. Then, the performance of the reactor was improved after the start-up period thus volatile fatty acids were further converted to biogas resulting from the increasing of pH value in the later phase. The overall pH was still in the suitable condition for the anaerobic reactor as the suitable pH range for anaerobic microorganisms is 6.5-8.5 (Metcalf and Eddy, 2003). The influent was an actual wastewater which taken from a seafood processing factory. It contained a high concentration of SS which was in the range of 550-1,000 mg L^{-1}. In this study, the removal efficiency of TSS was not considerable. Maybe, the high up-flow velocity and internal circulated flow caused the disorder inside the reactor resulting high concentration of suspended solids. In addition, the high up-flow velocity could also make the shear of the biomass layer that attached on PVA-Gel to the liquid phase and move up. Therefore, it is proposed that the effluent of IC reactor is needed to establish a further step to complete removal of TSS before discharging to the natural.

3.2 Chemical oxygen demand (COD) removal

The summary of COD concentration in influent and effluent is shown in Figure 2. The COD level in the influent was stable in the range of 3,880 – 4,250 mg L^{-1}, whereas the concentration of COD in the effluent changed during the time course. Within 72 days of the operational period, the organic loading rate was increased from 5 to 20 kg COD m^{-3} d^{-1} in 4 phases. The results showed that, in each level of OLR, the removal efficiency was low at the start and improved after that. When the reactor showed no significant changed of removal rate in 5 d operation the experiment was changed to the next phase. During the start-up of the experiment, the reactor was operated at OLR as 5 kg COD m^{-3} d^{-1}, the COD removal efficiency was about 30 % on the1st day and reached 73 % on day 18th. From day 19th the OLR was upgraded to 10 kg COD m^{-3} d^{-1}, the removal rate dropped to 45% and improved to achieve 85.4 % at the stable period. The performance of the reactor has the same tendency at OLR of 15 kg COD m^{-3} d^{-1}. When OLR was brought to 20 kg COD m^{-3} d^{-1} the removal efficiency was sharply declined to 30 % at day 55th. Then it gradually recovered in the next days and obtained the maximum value as 72 % on day 72nd of the experiment. At this day, the COD in the effluent was 1,206 mg L^{-1}. This concentration was high and need to reduce further before discharging to the aquatic environment. Many authors demonstrated that this model performed well at removing COD from wastewater. Wang at al. (2014) indicated that IC model could achieve maximum removal efficiency as 83 %; 70 %; and 75 %; at OLR of 5; 10; 14 kg COD m^{-3} d^{-1}. An internal circulation anaerobic reactor treating synthesis wastewater at high organic loading rate was investigated and obtained the COD removal 90% in the range of OLR as 2.50 - 12.12 kg COD m^{-3} d^{-1}, and it was dropped to 85 % when OLR was increased to 15.15 - 18.94 kg COD m^{-3} d^{-1} (Luo et al., 2016). In the treatment of high organic loading rate wastewater, many authors have been applied the combination of IC model following by an anoxic and aerobic treatment stage to enhance removing of the organic pollutants.

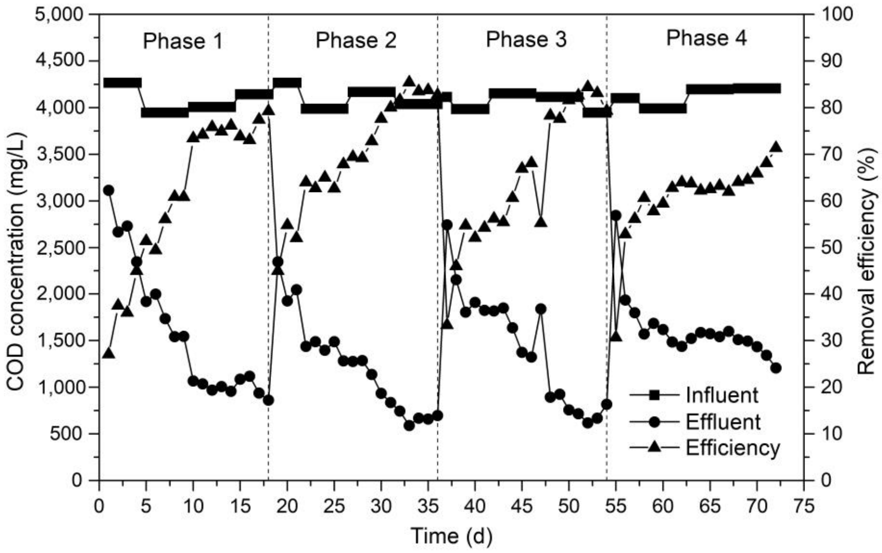

Figure 2: The profile of COD concentration during time course

3.3 Nutrient removal

Fig. 3 describes the concentration and removal rate of total nitrogen and total phosphorus during time course. It shows that the TN removal efficiency was decreased at the start, gradually increased after that and became stable at the end of each phase. The maximum of TN removal rate was 48 % at OLR 10.0 kg COD m^{-3} d^{-1}, the model minimum TN concentration in the effluent was 22.1 mg L^{-1}. The total phosphorus removal efficiency was not significantly changed when OLR was increased from 5 to 20.0 kg COD m^{-3} d^{-1} after 4 phases. The maximum TP removal rate was 30 % at OLR as OLR 10.0 kg COD m^{-3} d^{-1}, the minimum TP concentration after treatment was 12.5 mg L^{-1}. Those results demonstrated that IC model is not good at removing nitrogen and phosphorus-containing in wastewater. Perhaps, the consuming nitrogen and phosphorus in the reactor were used for metabolic to produce new cells of microorganisms. The anaerobic digestion reactors do not provide an environment for the conversion of different nitrogen forms in the nitrogen cycle. Many authors suggested combining treatment in anaerobic, anoxic, oxic processes could be beneficial for the removal of TN and TP in bioreactors. Because, in the oxic condition, the nitrification process occurs and converts ammonia nitrogen to nitrate; in the anaerobic and anoxic condition nitrate is converted to nitrogen gas through the denitrification process. Therefore the integration of those processes together with inner-circulation can enhance nitrogen removal efficiency (Chen et al., 2019).

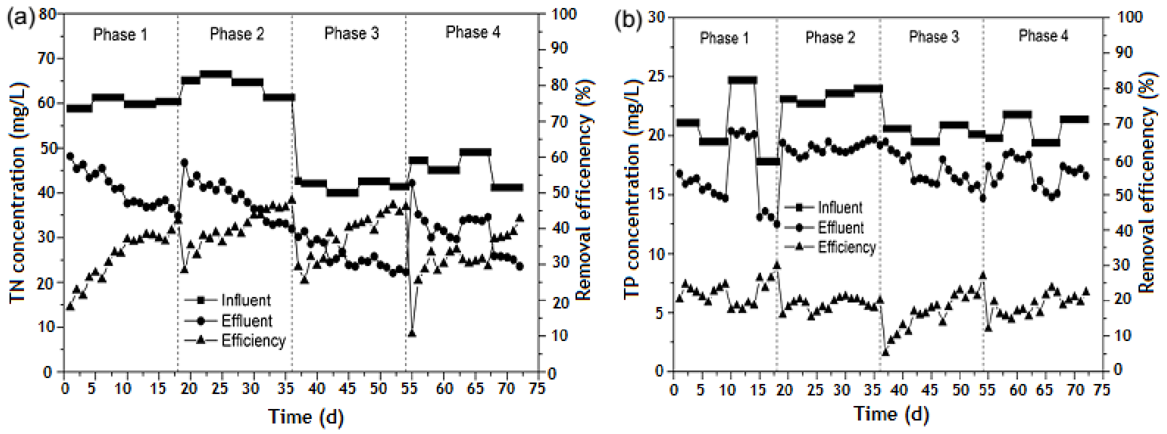

Figure 3: The nutrient removal efficiency during time course: (a) Total nitrogen; (b) Total phosphorous

3.4 Biogas production

Biogas production directly implies the performance of an anaerobic reactor (Bong et al., 2018). In this process, biodegradable compounds are converted to biogas through several steps such as hydrolysis, acidogenesis, acetogenesis and methanogenesis (Camacho and Ruggeri, 2018). Figure 4 shows the biogas production rate (BPR) and biogas yield (BY) during the operational time of IC reactor. During the steady stage of each level of OLR, the methane percentage in biogas was stable in the range of 61-65 % (data is not shown). The maximum BPR (L day^{-1}) was 23.1; 44.8; 93.7 and 93.8 at the OLR as 5; 10; 15 and 20 kg COD m^{-3} d^{-1}. BPR was increased when increased of OLR from 5 to 15 COD m^{-3} d^{-1}. When OLR was increased to 20 kg COD m^{-3} d^{-1}, BPR was not significantly increased. The maximum BY (m^3 biogas/kg COD added) was 0.19; 0.18; 0.25; and 0.19 at the OLR as 5; 10; 15 and 20 kg COD m^{-3} d^{-1}. Interestingly, the BY was not a linear relationship with the increase of organic loading rate. The maximum yield was achieved at OLR 15 kg COD m^{-3} d^{-1}, and it was not improved in the next phase even though the feeding organic concentration was increased. Wang et al. (2014) applied IC models to treat dyeing wastewater. The results showed that the biogas production reached 7 and 95 L d $^{-1}$ wat OLR 4.2 and 15.0 kg COD m^{-3} d^{-1}. Su et al. (2017) investigated the effect of temperature on the performance of an IC anaerobic reactor for the treatment of cassava wastewater. The results indicated that the reactor obtained the biogas production rate (L biogas day^{-1}) as 42; 30; and 9.84 at the temperature as 35; 30; 20 °C. The BPR was variable among different studies. This can be attributed that the different of reactor structures, wastewater types, operational conditions effected on experimental results (Dinh et al., 2019).

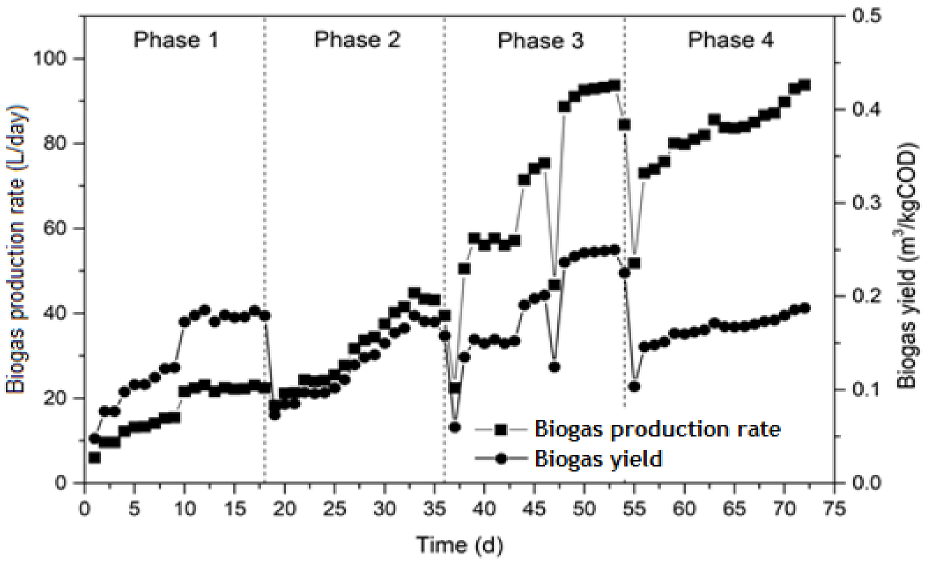

Figure 4: Biogas production rate during time course

4. Conclusion

The performance of an internal circulation anaerobic reactor treating food processing wastewater was investigated at organic loading rate as 5; 10; 15 and 20 kg COD m^{-3} d^{-1}. The results demonstrated that OLR have significant effect on COD removal efficiency and biogas production rate. The IC reactor could perform stably at OLR up to 20 kg COD m^{-3} d^{-1} with strength influent wastewater. The maximum COD removal rate was 85.4 % at OLR as 10 kg COD m^{-3} d^{-1} and the highest biogas yield was 0.25 m^3 biogas/kg COD. The results also indicated that this model was not good at removing TSS, TN and TP containing in wastewater. This study revealed a potential of internal circulation anaerobic in treatment of wastewater containing high organic concentration at high organic loading rate. It is suggested to investigate an integrated model between IC model and other bioreactor for improving the treatment efficiency of high-strength wastewater.

Acknowledgments

The authors would like to express their sincerest thanks to Vietnam Ministry of Natural resource and Environment for the financial support; Ho Chi Minh City University of Natural resource and Environment for accommodating the experimental facilities.

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