Optimization Removal of COD and Nitrogen at Different Hydraulic Retention Times in Biocord-Integrated Fixed-Film Activated Sludge System

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ABSTRACT

Although conventional activated sludge has been demonstrated to be a feasible approach for extracting nitrogenous chemicals and organic pollutants from wastewater, it still has a number of drawbacks. In this research, a pilot-scale biocord-integrated fixed-film activated sludge (Biocord-IFAS) reactor fed with actual domestic wastewater was operated to examine the effect of varying hydraulic retention time (HRT) on the COD and nitrogen removal. The type of material employed in this study is fibrous polypropylene (biocord), which is a major difference. The contribution of the Biocord-IFAS to COD removal efficiency reached 94.2% at HRT of 8 h and gradually decreased to 82.9% when HRT was reduced to 4 h. During the investigation period, a slight decrease in nitrification was found at a shorter HRT. The NH_4^+-N removal efficiencies at HRTs of 10, 8, 6, and 4 h were 97.8%, 98.7%, 97.1%, and 96.3%, respectively. The average effluent nitrate concentration was 5.3 mg/L with HRTs from 10 to 6 h, but over 30 mg/L with an HRT of 4 h. The SEM analysis results show that microorganisms have formed on the biocord surface. The results of this research have demonstrated the potential application of IFAS reactors in bioremediation procedures employing biocord material with great processing efficiency.

1. INTRODUCTION

Hitherto, biofilm methods are rapidly being used in wastewater treatment due to their advantages, such as reduced reactor sizes, ease of operation, less demanding solids separation needs, and improved specialization of attached biomass. The integrated fixed-film activated sludge (IFAS) method is one of these technologies. This process is an integration process that includes both suspended and attached growth (Kim et al., 2010; Mahendran et al., 2012; Malovanyy et al., 2015). By adding a fixed media to a suspended growth basin, the IFAS system boosts the microbial population and accelerates the biodegradation of organic compounds, making it one of the most common modified activated sludge processes (Kim et al., 2010). The biomass attached to the bio-carriers is kept within the system, which is a fundamental advantage of the IFAS method over traditional activated sludge procedures. The IFAS system is a viable alternative for upgrading activated sludge systems, particularly if land is limited. (Eslami et al., 2018). In comparison to ordinary activated sludge, the IFAS process has a higher COD and nutrient removal efficiency.

Previous studies have shown that the IFAS system is effective in removing nitrogen from wastewater (Onnis-Hayden et al., 2007; Shao et al., 2017). Furthermore, the IFAS process has exhibited consistent nitrification at much lower mixed liquor contents than the standard activated sludge process can produce. As is well known, nitrification is divided into two steps: In the first, ammonium is used by autotrophic ammonia-oxidizing bacteria (AOB) to make nitrite, and in the second, nitrite is oxidized to

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nitrate by nitrite-oxidizing bacteria (NOB) (Xu et al., 2014). A high COD promotes heterotrophic growth and increases competition for space and oxygen between heterotrophs and autotrophic nitrifying bacteria (Bassin et al., 2012; Kim et al., 2011; Onnis-Hayden et al., 2011). This has affected the nitrification efficiency negatively. Bio-carriers are added to conventional activated sludge reactors in the IFAS design to provide surface area for microorganism attachment and growth. The support media in the IFAS reactor can also provide longer sludge retention time (SRT) than the traditional activated sludge process, allowing slow-growing nitrifying growth and promoting nitrification (Shreve and Brennan, 2019). As a result, combining the properties of suspended and attached growth processes by using specifically designed biomass carriers for simultaneous COD and nitrogen removal is more appealing.

However, because IFAS is a new technology, there are still some studies in the literature that are limited. There is a knowledge gap regarding the impact of several operational variables on removal performance and bio-carrier activity characteristics. The goal of this study was to see how different HRT parameters influenced the performance of a biocord-IFAS reactor in the short term. The purpose of this study was to assess the treatability of COD and nitrogen in real home wastewater utilizing an IFAS reactor system with bio-cords as bio-carriers.

2. METHODOLOGY

2.1 Characteristics of wastewater

The raw wastewater was collected from the storage tank of Co May dormitory in Vietnam. The characteristics of the dormitory wastewater are shown in Table 1.

Table 1. Characteristics of influent wastewater used in the research

Parameter	Unit	Range (n=3)
pH	-	6.9±0.3
SS	mg/L	195±5
DO	mg/L	0.4±0.1
BOD_5	mg/L	201.6±2.5
COD	mg/L	335.9±4.1
$N\text{-}NO_3^-$	mg/L	0.30±0.01
$N\text{-}NH_4^+$	mg/L	70.4±1.2
TP	mg/L	4.9±0.9

2.2 Experimental apparatus

The pilot-scale Biocord-IFAS system employed had a similar design as previously described in Nhut et al. (2020). Figure 1 shows the Biocord-IFAS reactor which is composed of transparent glass sheets with a thickness of 8 mm and a useful volume of 27 L. The Biocord media used in this research was made of a polypropylene fibrous bundle with a specific surface area of 1.6 m^2/m (commercial code: MK-PP50, Bishop Water Technologies, Canada). The total 2 m length of Biocord was installed in an IFAS tank. In detail, the wastewater was fed into the reactor from the sewage tank by a peristaltic pump. The bioreactor was operated at various HRT of 10, 8, 6, and 4 h. The sludge retention time (SRT) was 10 days. The organic loading rate (OLR) was from 0.5 to 1.5 kg COD/m^3/day. The return activated sludge (RAS) rates were chosen from 1 to 1.5Q. The average DO concentration was maintained at 5.5±0.5 mg/L.

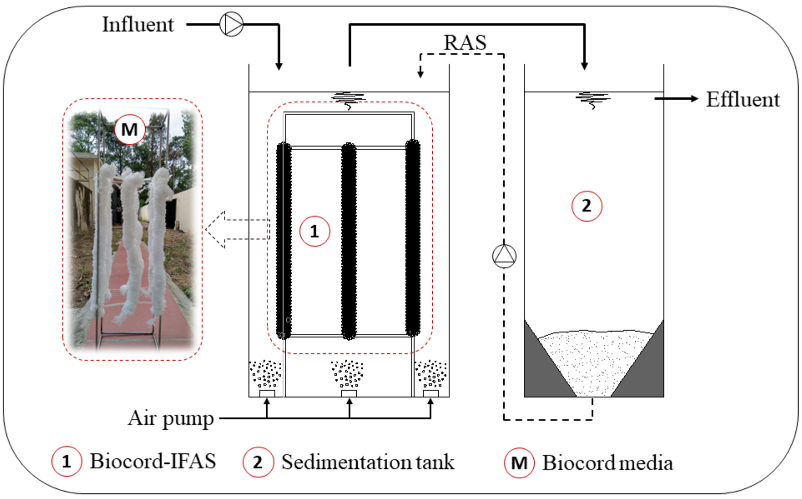

Figure 1. Diagram of the Biocord-IFAS system.

2.3 Analysis methods

In this research, the "Standard methods for examining water and wastewater" (Baird et al., 2017) was used for the determination of BOD_5 (5210B), COD (5220D), nitrate (4500-NO_3^-), nitrite (4500-NO_2^-), ammonium (4500-NH_3), suspended solids (2450B), and total phosphorus (4500-P). DO and pH were directly tested by Water Quality Checker WQC-22A (DKK-TOA, Japan). Moreover, Scanning Electron Microscopy (SEM, S-4800, HI-9039-0006, Hitachi, Japan) was used to prepare images of the biofilm. In addition, this study utilized the most common statistical descriptive parameters such as mean and standard deviations (±SD). The data were analyzed by the SPSS 22 software package for Windows (SPSS Inc., Chicago, IL, USA).

3. RESULTS AND DISCUSSION

3.1 Overall performance of start-up phase

The start-up test operated for 15 days with a hydraulic retention time (HRT) of 10 h. The average efficiencies, as well as influent and effluent quality, are presented in Table 2. The COD and ammonium removal efficiencies were 79.5±3.3% and 86.2±0.9%, respectively, in Biocord-IFAS reactors. Additionally, attached biomass growth also achieved a steady state. The MLSS concentration of mixed liquor was steady at 2,675±150.4 mg/L. For the biocord, the biofilm was mainly developed on the outer surface of the carrier. However, the biocord possesses a large surface area that microorganisms can attach in the cords, and then develop over surface areas.

Table 2. Performance of treatment during the start-up test

Parameter	Influent (mg/L)	Effluent (mg/L)	Efficiency (%)
COD	230.1±15.8	46.7±5.6	79.5±3.3
N-NH_4^+	53.9±2.5	7.4±0.2	86.2±0.9
SS	115.7±6.2	27.7±1.1	76.0±1.7

3.2 COD removal

The removal of COD in the Biocord-IFAS system was evaluated at different HRT as illustrated in Figure 2. The removal efficiency of COD ranged between 82.9% and 94.2% with HRT ranging from 4 to 10 h. The average effluent of COD concentration was 37.2±14.4 mg/L for the operated HRTs. A similar observation was reported by Dang et al. (2020), who suggested the effluent COD from loofah sponges as a bio-carriers in the IFAS system for the treatment of municipal wastewater was maintained at a level of 35.2±18.9 mg/L, despite a change in the HRT from 3 to 7 h. The COD removal was maintained at 92.2±2.5%, 94.2±1.6%, and 91.7±2.9% at HRT of 10, 8, and 6 h, respectively, but was 82.9±3.0% at an HRT of 4 h, which indicates that the HRT affects the COD efficiency removal. This result agreed with Singh et al. (2015), who reported that the IFAS maintained an average removal rate of ~92% for COD at HRT of 6.9 h. In addition, Eslami et al. (2018) reported the best removal efficiency of COD was 92.52±4.33% at HRT of 10.8 h.

The effluent COD concentration not only complies with the Vietnam National Technical Regulation on Industrial Wastewater, QCVN 40:2011/BTNMT (75 mg COD/L, column A), but also reaches the Vietnam National Technical Regulation for surface water quality, QCVN 08:2008/BTNMT (50 mg COD/L, column B2). Furthermore, the organic content in the effluent was removed to an acceptable level for reuse such as park irrigation, flushing a toilet, or aquaculture recirculation.

3.3 Nitrogen removal

The variation of NH_4^+-N and NO_3^--N in the dormitory wastewater treated using Biocord-IFAS are shown in Figure 3. During the investigation period, the NH_4^+-N removal efficiencies at HRTs of 10, 8, 6, and 4 h were 97.8±1.1%, 98.7±1.1%, 97.1±1.7%, and 96.3±0.8%, respectively, which implies a slight decrease in nitrification at a shorter HRT. This result agreed with Sriwiriyarat et al. (2008), who reported the IFAS system with a 0.6 m^2 of 2.54 cm Bioweb media could always maintain ammonium removal efficiencies greater than 95% at HRT of 6-10 h. Furthermore, the effluent NH_4^+-N concentration throughout the study period remained low, averaging 1.0±1.1 mg/L, which complies with the Vietnam National technical regulation on domestic wastewater, QCVN 14:2008/BTNMT (5 mg NH_4^+-N/L, column A). Notably, there were a few days when the ammonia concentration in the effluent was lower than detectable (less than 0.4 mg/L), indicating that nitrification had occurred completely.

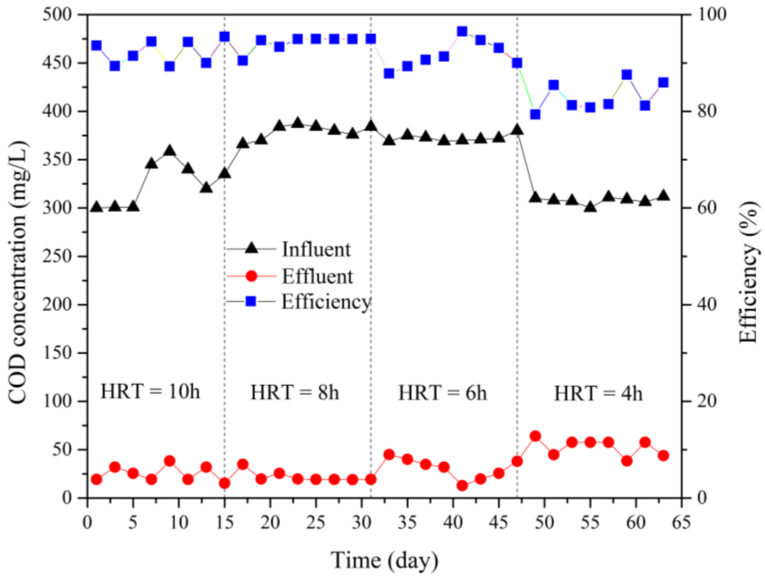

Figure 2. Variation of COD concentration at different HRTs

The average effluent nitrate concentration was 5.3±2.0 mg/L with HRTs from 10 to 6 h, but over 30 mg/L with an HRT of 4 h. At short HRT, the denitrification process is not efficient because the organic carbon source is not sufficient for the metabolic heterotrophic microorganisms. One possible explanation was that low COD concentrations inhibited the bioactivities of heterotrophic denitrifiers. On average about 3.4% of nitrate was denitrified at HRT of 4 h. The effluent nitrite concentrations generally remained at less than 0.5 mg/L (data not shown) across all HRTs illustrating that there was no nitrite accumulation in the IFAS tank. This suggested that very short HRT was unconducive to the contact between pollutants degradations and the biofilm. Meanwhile, residual organics in wastewater inhibited the activity of nitrifying bacteria, which eventually led to an inefficient nitrogen removal.

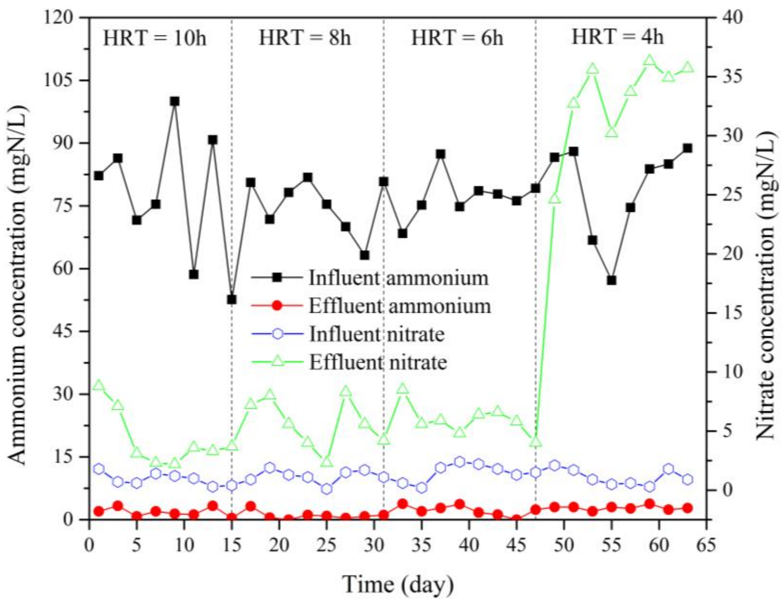

Figure 3. Variation of nitrogen concentration at different HRTs

3.4 Biofilm formation on the bio-carriers

After over 60 days of use in experiments, bio-carriers in the IFAS reactor were removed to observe biofilm formation. Figure 4 shows the SEM image before and after biofilm formation on the surface biocord in the IFAS reactor. Many gaps between the polypropylene fibrous bundle can be seen in Figure 4 (a), providing a highly porous surface area for the adhesion and trapping of microbial cells. For bio-carrier materials, the important parameters affecting microbial colonization are the surface area and the ability to adhere. Figure 4 (c and d) show the formation and development of microorganisms on the biocord surfaces. These biofilms as surface-associated communities of microorganisms could play a great role in the bio-oxidation of organic pollutants especially in the IFAS by means of a large surface area for biomass accumulation. Indeed, Kim et al. (2011) also showed that in the IFAS system, the ammonium removal rate was better than that of conventional activated sludge.

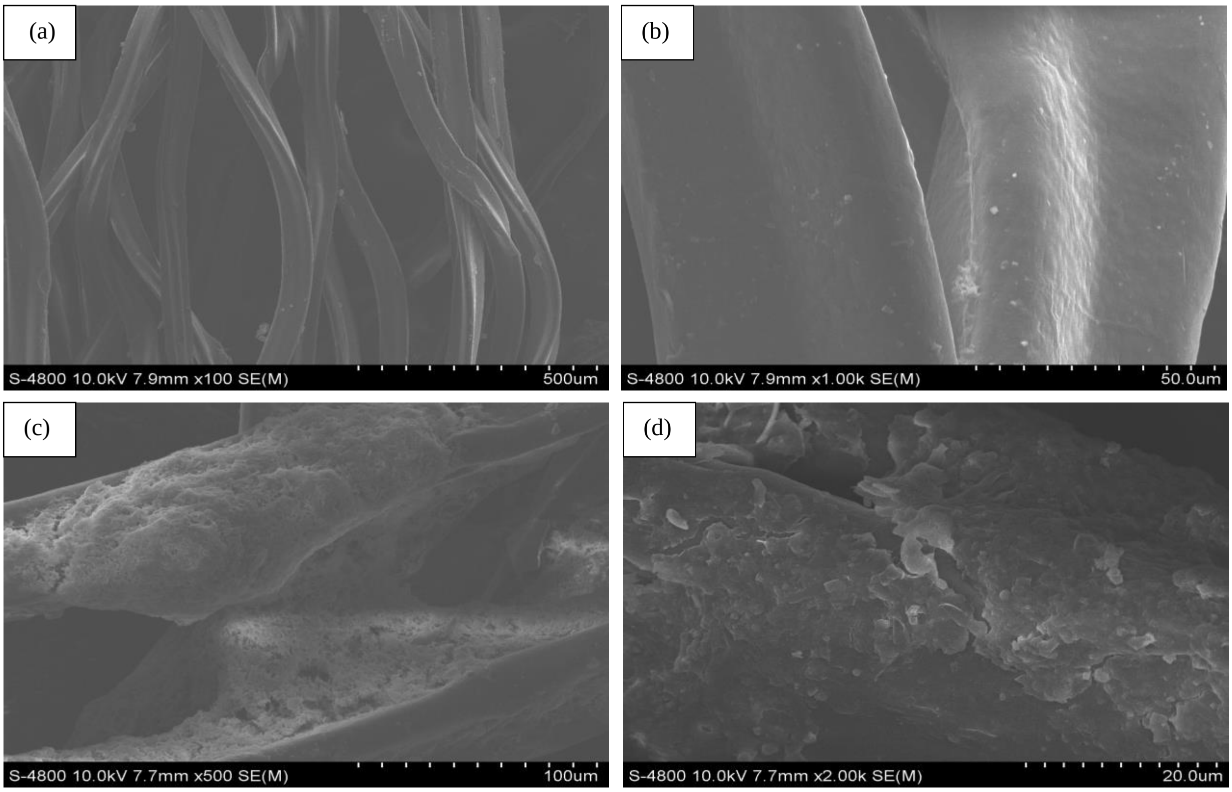

Figure 4. SEM images from biocord within IFAS reactor, (a, b) before biofilm formation, (c, d) after biofilm formation

3.5 Comparison of domestic wastewater treatment performance between IFAS technologies

Table 3 shows a summary of IFAS performance for domestic wastewater treatment between different studies. As shown in Table 3, a variety of materials have been used as carrier media. They are loofah sponge, non-woven polyester, PE, plastic, and biocord. According to the report of Lariyah et al. (2016), the material of carrier media was vital and affected the microbial ecosystem. Furthermore, the filling ratio is important to control microbial activity. It ranges from 10% to 50% selected as a function of IFAS configuration (Table 3). On the other hand, Leyva-Díaz et al. (2017) indicated the filling ratio affects the HRT and SRT (from a few hours to a few days) because of the volume occupied by the media. Under a high filling ratio, IFAS can accomplish high nutrient removals due to higher SRT and higher biofilm amount. The notable difference in this study is the type of material used, which is fibrous polypropylene (biocord). With outstanding properties such as large surface area, high biocompatibility, high durability and large size, it will limit washout in the outlet stream. This has shown the potential application of biocord material with high processing efficiency in bioremediation processes.

Table 3. Summary of IFAS technology for treatment of domestic wastewater

Type of reactor	DO (mg/L)	HRT (h)	SRT (day)	Type of carrier	Media filling ratio (%)	Performance	References
Pilot-scale IFAS	7	4-10	10	Biocord MK-PP50	10*	COD removal >95%, NH_4^+-N removal >95%	This study
Pilot-scale IFAS	NA	12.5	13.5	Acrylic fiber	20	COD removal >80%, NH_4^+-N removal >95%	Xu et al. (2021)
Pilot-scale IFAS	NA	3-7	NA	Loofah sponge	30	COD removal 83%, TN removal 71%	Dang et al. (2020)
Pilot-scale IFAS	2.2-6.3	24	4-10	BMX1	43	COD removal >90%, effluent NH_4^+-N 1 mg/L	Moretti et al. (2018)
Lab-scale SNAD-IFAS	0.4-0.6	18	20	Non-woven polyester ring	40	COD removal 64.8%, TN removal 45-70% (71.4-79.4 mg/L), TOC removal 44.7-91.4%	Wang et al. (2018)
Lab-scale IFAS-SFD-MBR	2-4	8	30	PE carrier	19	COD 26.0±3.5 mg/L (>90%), TN 28.7±5.0 mg/L, NH_4^+-N <1 mg/L, NO_3^--N 28.4±4.4 mg/L, TP 7.2±1.5 mg/L	Vergine et al. (2018)
Lab-scale IFAS-SBR	7-8	12.8	NA	Bioflow 9	50	COD 10-20 mg/L (98.6±1.5%) and NH_4^+-N <0.1 mg/L (99.93±0.004%)	Shao et al. (2017)
Lab-scale IFAS-SBR	NA	6.5	NA	Cubic sponge	25	COD removal 85% (57 mg/L), TN removal 85%	Gu et al. (2017)
Lab-scale IFAS	0.7-1.5	18-58.8	NA	AnoxKaldnes K1	40	TN removal 70±4% at sCOD/NH_4^+-N 1.8±0.2, effluent ammonium 9.2 mg/L, nitrogen removal rate 55±6 g N/(m^3/day)	Malovanyy et al. (2015)
Full-scale IFAS	3-5	NA	4.8	AnoxKaldnes K3	50	TN 9.95 mg/L (75.1%), NH_4^+-N 1.6 mg/L, NO_3^--N 8.4 mg/L	Regmi et al. (2011)

Note: NA-not available; (*) SRT for activated sludge without Biocord

4. CONCLUSION

According to the results above, it is obvious that using the Biocord-IFAS reactor can effectively remove nitrogenous compounds and organic contaminants from domestic wastewater. Meanwhile, the HRT plays a key role in the system, and the optimized solution was an HRT of 8 h. Under such conditions, the removal efficiency of COD and ammonium were 94.2±1.6% and 98.7±1.1%, respectively. Analysis of the SEM images also showed the development of microorganisms on the biocord surfaces. These surface-associated communities of microorganisms could play a great role in the bioreactors. The effluent concentration not only complies with the Vietnam National technical regulation on domestic wastewater, QCVN 14:2008/BTNMT, but also reaches the Vietnam National Technical Regulation for surface water quality, QCVN 08:2008/BTNMT and the Vietnam National Technical Regulation on Industrial Wastewater, QCVN 40:2011/BTNMT. Thus, the use of the biocord as a biofilm carrier in an IFAS reactor can be an effective wastewater treatment alternative to activated sludge.

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