Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(6):1394-1399

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Performance tests of a novel suspended carrier biofilm reactor

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ABSTRACT

A novel reactor characterized by the addition and internal loop of carrier was developed and its performance was examined with synthetic domestic wastewater. The internal loop was achieved by injecting air through a gas aerator located at the reactor bottom, the aim was to produce aerobic and anoxic area in the reactor and bring about the nitrification and denitrification in a single reactor. The COD，NH_4^+-N and TN removal efficiency in the reactor and the biomass change on the carrier were investigated, COD removal efficiency of 80% was achieved in three weeks after the initiation of the reactor, the biomass on the carrier peaked 7.27kg/m^3 after 55 days. The reactor had a steady COD removal efficiency with an average removal rate of 80% at the influent COD range of 200-600mg/L, or at the COD volumetric load of 0.71-2.16 kgCOD/m^3.d; the maximum removal of NH_4^+-N and TN were 97.7% and 52.5%. The test results showed the novel reactor effectively removed TN and COD in domestic wastewater, it can realized the simultaneous nitrification and denitrification (SND) process by adjusting the macro-environment and the stratification of bioflim in a microscopic scale in the reactor.

Key words: Wastewater treatment; Nitrification; Denitrification; Circulating suspended carrier, airlift reactor

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INTRODUCTION

Many studies have shown the advantages of small integrated wastewater treatment equipments used to domestic wastewater treatment and reclamation projects, such as high energy efficiency, easy operation and maintenance, less space demand [1, 2]. Reduction of the reactor volume often associates with the addition of small suspended carrier with high specific surface to the conventional activated sludge system as biofilm support, the suspended and attached biomass grow simultaneously in such hybrid bioreactor and a high biomass level is retained. Moreover, the attached biomass lead to a long solid retention time (SRT) in the system and the Nitrifiers with a long generation time can be maintained in the system and enhance the nitrification [3, 4]. The total nitrogen removal from domestic wastewater is always fulfilled by nitrification and denitrification processes at aerobic and anoxic reactor separately in the multi-reactor systems, recirculation of mixed liquor from aerobic to anoxic reactor is required, such as Anoxic/Oxic process. In recent years, simultaneous nitrification and denitrification (SND) has been found and studied in different systems, it can remove the nitrogen in a single bioreactor [5-9]. But the SND was achieved using flexible biofilm fixed in the reactor or biodegradable carriers and the realization of SND needed onerous control and adjustment of operation parameters such as DO and organic load, the TN removal was often achieved in a big reactor with different functional part like the Anoxic/Oxic process, or by the external recirculation of nitrate liquor from aerobic zone to anoxic zone. In this study, a novel suspended carrier biofilm reactor combined the advantages of the activated sludge and biofilm process was designed. The carrier in the reactor was circulated by aerating partially at the reactor bottom, the purposes of the design was to create proper sludge macro-environment and bioflim micro-environment for the nitrogen and organic matter removal. The aerobic and anoxic macro-environment in the reactor can be produced by controlling the aeration density, and the stratification of bioflim can provide a micro-environment for SND. The performance of the novel reactor was examined using synthetic wastewater and focus was kept on organic matter and nitrogen removal.

STRUCTURE OF THE NOVEL REACTOR CARRIER

Experimental reactor was made of plexiglass column, the structure diagram was shown in Fig.1, the total column height was 2.74 m with a diameter of 0.30 m, the total reactor volume is 168.6L and reaction zone volume was 138.0 L. The entire device was divided into the support layer, the reaction zone, and the top zone through bottom to top. The reactor was separated by a partitionin the middle and a semicircle hole was opened at both ends of the partition. Air from compressor wasdelivered to the support layer and then aerated via the perforated plate at the left part of the bottom. The carrier was circulated by the injected air and movedclockwise in the reactor. The synthetic wastewater was pumped to the top right portion of the reactor, then flowed into the right side of the reactor and circulated in the reactor driven by the carrier. The effluent moved through perforated plate at the top of the partition and the carrier was intercepted in the reactor. The outlet located at the top of the reactor.

Anoxkaldnes® suspended carrier made in Swedish has been used in this study. Anoxkaldnes carrier, shown in Fig. 2, was made of modified polymer materials with improved enzyme catalysis, it is well hydrophilic and easy to be colonized by bacteria and suspended in water. The porosity of the carriers is near 85% and the packing density is about 0.97 g/cm^3, its density is slightly smaller than that of water. The carrier has a large specific surface area of 1200 m^2/m^3. Some studies showed the packing rate of the carriers influenced COD removal slightly but affected ammonium removal heavily, the packing rate of 40% of polyurethane foam carriers in aerobic moving bed biofilm reactors was essential for ammonium removal[10], Eventually, the packing rate of 50% has been adopted in this test.

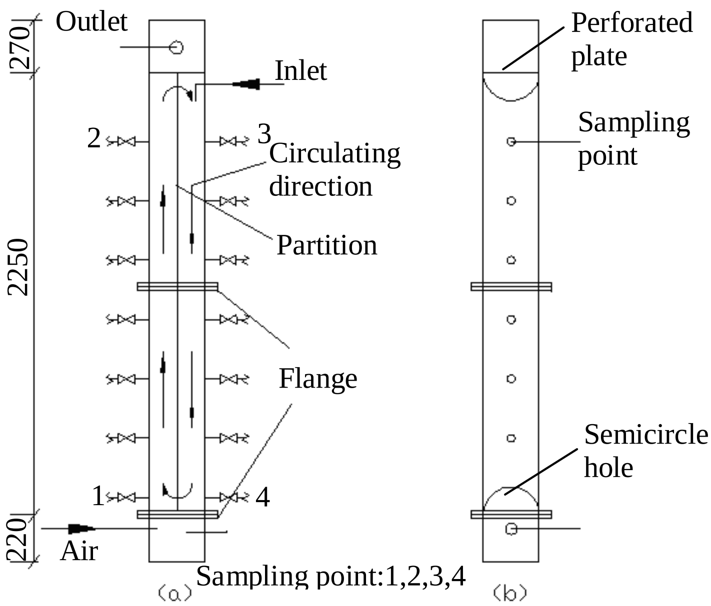

Fig. 1:Schematic structure of airlift reactor

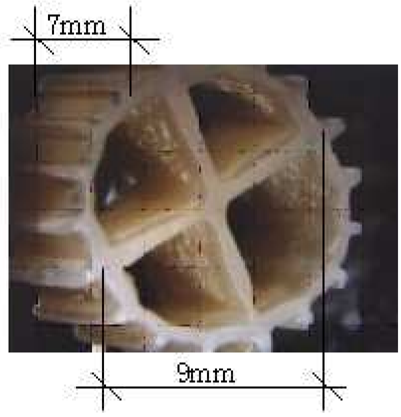

Fig. 2: Picture of Anoxkaldnes carrier

The dissolved oxygen (DO) level was different at the two partsin the reactor because the air was introduced at the bottom left part of the reactor, the right part of the reactor wasat non-aeration condition. The DO level at left part was higher than that of right part. Therefore, the right part of the reactor may keep amacro anoxic or even anaerobic condition. The reactor was divided into aerobic and anoxic zone, which provideddifferentproper environment for different types of microbial metabolism. Aeration densityhas a great impact on the flow rate and DO level of the liquid in the reactor

RESEARCH METHOD AND MATERIALS

The COD, NH_4^+-N, TN, and TP in influent and effluent were monitored based on the water and wastewater monitoring and analysis methods developed by the State Environmental Protection Administration of China[11]. DO in the different part of the reactorwas analyzed by a DO meter (HQ30d, Hach, USA).Biomass attached on the carrier was measured as following method:1) took a number of blank carriers into a weighing bottle, dried to constant weight at 105℃, weighted and calculated the average mass of the carrier;2) then took a certain number of carriers colonized withbiofilm into weighing bottle, dried to constant weight at 105℃, weighted and calculated the average mass of the carrier; 3) The difference between the two weights was the biofilm massattached on carriers.

The synthetic domestic wastewater was prepared with anhydrous sodium acetate, ammonium chloride, and potassium dihydrogen phosphate for organic matter, nitrogen, and phosphorus respectively. Some trace elements were also added to enhance the microorganisms growth. The chemical reagents employed to produce wastewater were listed in table 1.

Table 1: The composition of simulated wastewater

Reagent	Content	Reagent	Content
C_2H_5OONa	100-600 (mgCOD/L)	H_3BO_3	0.05 (mg/L)
NH_4Cl	20-40 (mgN/L)	$CuSO_4.5H_2O$	0.01 (mg/L)
KH_2PO_4	3.0 (mgP/L)	KI	0.06 (mg/L)
EDTA-2Na	3.33 (mg/L)	$MnCl_2$. $4H_2O$	0.04 (mg/L)
$FeCl_3.6H_2O$	0.5 (mg/L)	$ZnSO_4.7H_2O$	0.04 (mg/L)
$CoCl_2.6H_2O$	0.05 (mg/L)	$NaMoO_4.2H_2O$	0.02 (mg/L)

RESULTS AND DISCUSSION

BIOFILM COLONIZATION ON CARRIERS

The biofilm colonization of the microorganisms on carriers was critical for pollutants removal. During the biofilm colonization process, theinfluent flowrateand COD was kept at 20L/hand 300mg/L respectively, the hydraulic retention time in reactor was 6.9h, and the COD in effluent was analyzed weekly. The ratio of air and water was 10:1, the air flowrate was 200L/h. The COD removal overbiofilm colonization process was shown in Fig.3. The reactor had a COD removal efficiency of 80.2% after 3 weeks, which increased to 88.3% after 5 weeks and kept stably.

CHANGES OF THE BIOMASS ON THE CARRIERS

Over the biofilm forming process, the biomass on the carriers was measured by every five days, the result was shown in Fig. 4. It indicated the average amount of the biomass was increasing with the time increase of biofilm colonization, the average biofilm amount on the carrier reachedto the peak of 7.2 mg/each carrier after 60 days, the biomass adhered on the carriers was 7272mg/L reactor volume , the suspended solid in the reactor was 260.8mg/L, so the total biomass in the reactor reached 7532.8mg/L. Compared to the conventional activated sludge process, the biomass in the reactor was much higher and the thickness of the biofilm was about 2.52mm, the DO, COD and NH_4^+, NO_X^- had a content gradient from the surface to the interior of the bioflim and created the environment for the occurrence of the SND. Research onflocsin the activated sludge process indicated the SND would occur in the flocs with a diameter of approximately 3000μm [12]. In this study, the thickness of the biofilm on carriers was about 2.52mm after 60 days, so the micro-environment in carrier'sbioflimsuitable for the occurrence of SND.

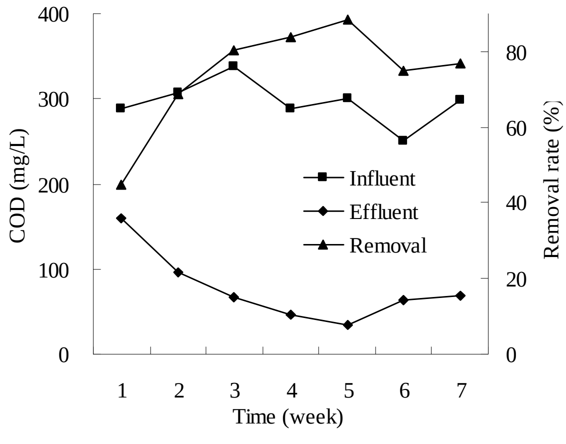

Fig. 3:COD removal over biofilm colonization

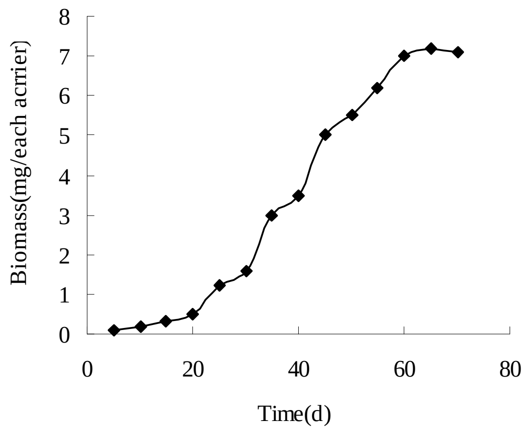

Fig.4:Biomass variations on the carrier

COD REMOVAL

The COD removal capacity of the reactor was tested after the success of bilofilmcolonization on carriers. keeping influent COD at the range of 200-600mg/L and the COD load was 0.71-2.16 kg COD/m3.d, DOwas controlled at 2.5-6.0 mg/L, the HRT=6.9h, theCOD in effluent wasillustrated in Fig. 5, the highest COD removal rate was 95.5%, and the average removal rate was 82.7%. When the COD of influent was 100 mg/L, the COD load of influent was0.36kg COD/m3.d, the COD in effluent was 6.0-55.0 mg/L, the highest COD removal rate was 97.8%. The experimental results showed the reactor hada strong adaptability to the COD load and a stable COD removal efficiency.

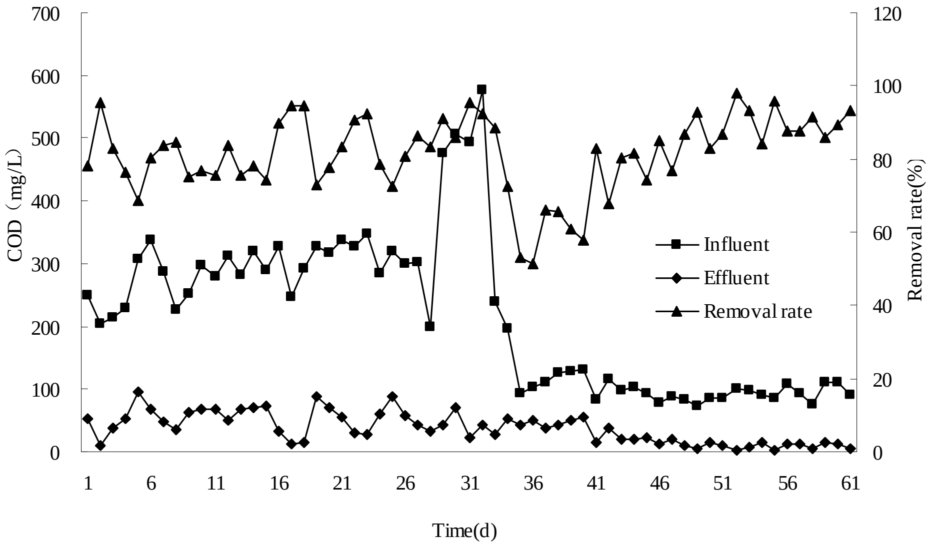

Fig. 5:COD removal capacity tests

AMMONIA REMOVAL

The ammonia removal by reactor was shown in Fig. 6. The wholetest process was divided into two stages based on the NH_4^+-N level in influent, when the NH_4^+-N=28.6-38.2mgN/L in influent, NH_4^+-N in effluent was 0.0-24.3mgN/L, the highest removal rate was 98.2% and average removal was 66%; when the influent NH_4^+-N=17.5-20.5mgN/L, NH4+-N in effluent was 0.0~3.0 mgN/L, the highest removal rate is 99% and average removal is 97.7 %. The reactor can achieve high ammonia removal by controlling the appropriate COD load and DO level. The NH_4^+-N removal was influenced by DO level and COD load. The oxidation of carbonaceous organic matter and nitrification of NH4+-N by microorganisms both consumed the oxygen in wastewater. High COD load and low DO level hindered the process of nitrification.

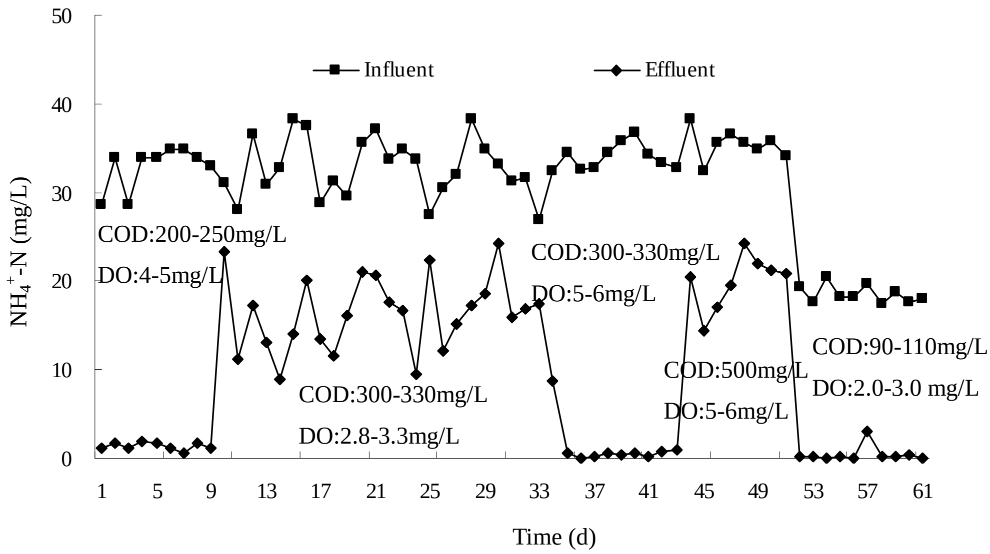

Fig. 6: Variation of NH_4^+-N in influent and effluent with the COD and DO changes

TN REMOVAL

The TN removal was presented in Fig. 7. When the influent TN=29-44.7 mgN/L, COD load was 0.72COD/m^3.d (COD≈200mg/L), and the DO in effluent was 3.9mg/L, the TN in effluent was 3.0-20.0mgN/L, the highest removal efficiency was about68% and the average removal rate was53.1%. The reactor achieved a relative high TN removal.The DO level in the four sampling point was shown in Fig. 8, the DO level in the left part was higher than that in the right part of the reactor, the reactor was divided into macro aerobic and anoxic zone.

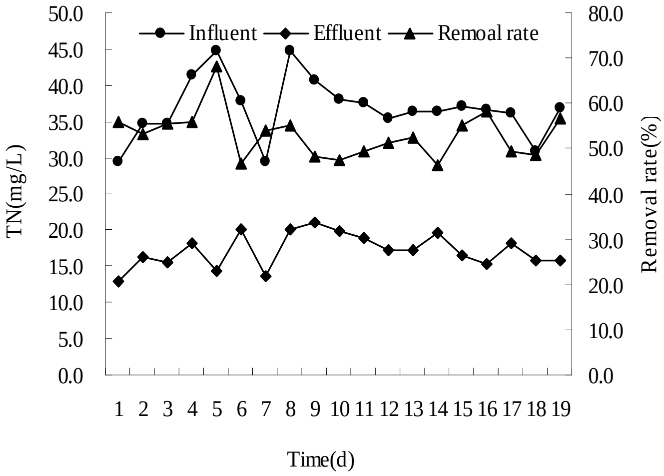

Fig. 7: TN removal by the reactor

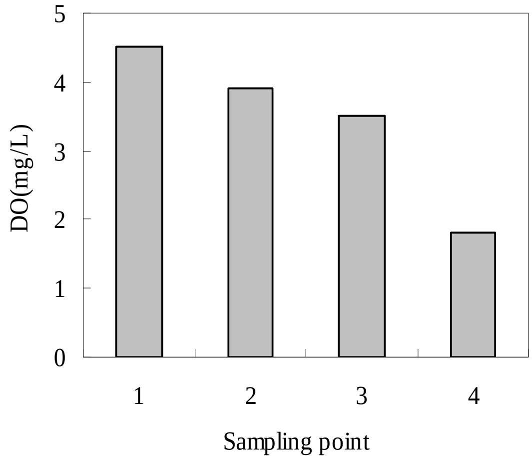

Fig. 8: DO level variation in the reactor

The DO level at samping point 4 was about 1.8mg/L, so the right part was also aerobic condition in the true sense. The Simultaneous nitrification and denitrification (SND) occurred in the biofilm might be the main reason for the TN removal. A study on biofilm-internal and external mass transfer resistance in nitrifyingsuspended carrier reactors indicated that oxygen mass transferresistance controlled the process performance up to a DO level of 20 mg/L. External masstransfer controlled the overall reaction rate [13]. In this study, the DO variation in the reactor enhanced the styles of the DO transfer model into the biofilm and the probability of SND occurrence.

TP REMOVAL

Controlling the same test parameters as in TN removal, The TP was 2.5-3.9 mgP/L in influent and that in effluent was 0.6-3.6 mg P/L, the average TP removal rate was 36.2% as shown in Fig. 9, microbial assimilation of phosphorus by microorganisms was the mainly way to remove TP.

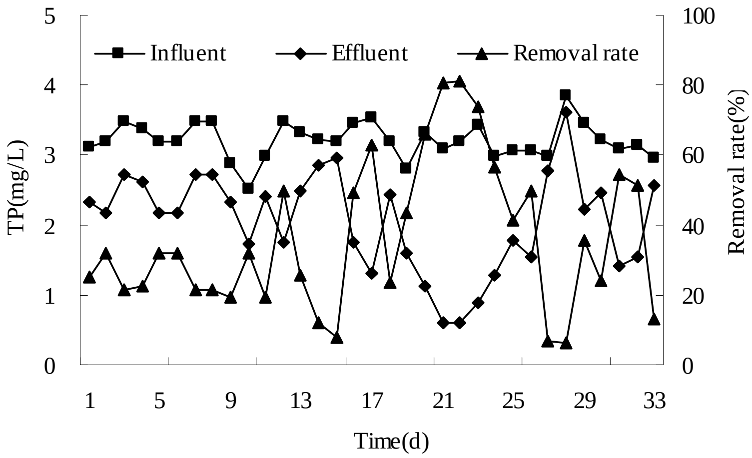

Fig. 9: TP removal by the reactor

CONCLUSION

The novel reactor had a big biomass on suspended carrier and the partial aeration at the reactor bottom circulated the carriers and sewage to form an internal loop, that operating patterns created the macro aerobic and anoxic zone in a single reactor and the micro biofilmenvironments suitable forthe SND.The reactor combined the features of continuous stirred tank reactor (CSTR) and plug flow reactor (FRR). It had an effective COD removal capacity at the COD range of 200-600mg/L with DO level of 2.5-6.0mg/L. the reactor achieved a 90% NH_4^+-N removal at the NH_4^+-N level of 28.6-38.2mgN/L in influent by controlling the appropriate DO and COD load. The average TN removal rate of 53.1% was accomplished ata TN level of 29.0-44.7mgN/L in influent and a COD loadof 0.72kgCOD/m^3.din the reactor.

Acknowledgments

The authors wish to thank the National Key Technology R&D Program from the Ministry of Science and Technology of China for contract 2012BAJ14B03, under which the present work was possible.

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