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Upgrading of Activated Sludge Systems Using Immobilized Nitrifiers in Polymer Pellets

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Abstract— The presence of excess nutrients in wastewater can cause eutrophication. Also, the presence of ammonia in some polluted surface water bodies lead to difficulty in chlorine disinfection. In conventional treatment processes, it is difficult to maintain high efficiency of simultaneous removal of ammonia and total organic carbon in a single reactor, because the simultaneous growth of nitrifiers and heterotrophs in the same reactor often leads to low nitrification. The use of immobilized microorganisms has been gaining importance because the activity of specific microorganisms can be enhanced to perform certain reactions; thus immobilized nitrifying cells in polymer pellets for enhanced nitrification can be used. Pellets made of synthetic polymers are superior to natural polymers in terms of strength and durability; their estimated life span is about 10 years. In this paper, nitrification using immobilized nitrifiers was examined by upgrading an activated sludge system using polyethylene glycol (PEG). The experimental work was carried out in Hitachi treatment plant. The results of the experimental works showed that PEG is a suitable material for immobilizing nitrifiers in terms of physical and biological characteristics, and the pellets with diameters (2 to 3) mm are fluidized sufficiently in the nitrification tank. High removal efficiencies of total nitrogen were obtained. The removal efficiency depends on hydraulic retention time, and recycle ratio. The reactor volume required when using immobilized nitrifiers can be reduced to be half that required by the conventional system, leading to reduction in the initial costs.

Index Terms— Biological nitrogen removal; Immobilized nitrifiers; Nitrification; Polyethylene glycol; Polymer pellets; Wastewater

1 Introduction

Discharge of wastewater is considered as one of the main causes of serious deterioration of surface water quality in many developing countries [1]. The presence of nutrients in wastewater, and their discharge without effective treatment into the water bodies can cause eutrophication [2-4]. Also, the presence of ammonia in some polluted surface water bodies lead to difficulty in chlorine disinfection such as increased process costs associated with increased chlorine dosage, difficult process control due to variable ammonia concentrations, formation of harmful disinfection by-products, chlorine-related tastes and odors and growth of nitrifying bacteria in drinking water distribution systems [5-9]. In recent years nitrification received much attention because of its environmental significance in the nitrogen cycle, in the greenhouse effect, in acid rain and in eutrophication [10-13]. Biological nitrogen removal (BNR) is commonly used in wastewater treatment plants involving two processes: nitrification (NH_4^+-N is oxidized to NO_3^- -N) and denitrification (NO_3^- -N is converted to nitrogen gas) [4, 14].

In conventional treatment processes, it is difficult to maintain high efficiency of simultaneous removal of ammonia and total organic carbon in a single reactor, because the simultaneous growth of nitrifiers and heterotrophs in the same reactor often leads to low nitrification [15]. This is because nitrifiers have a slower respiration rate than that of heterotrophs [16,17]. The generation time of nitrifiers is about 15 hours, while heterotrophic microorganisms have a generation time of 20-40 minutes [18,19]. Temperature is also an essential factor that influencing the ammonia removal rates [20-23]. In previous researches, the temperature coefficient for suspended growth systems was found to be 1.076 [24,25]. On the other hand, the decrease in saturated dissolved oxygen (DO) concentration, as temperature increases, results in a decreasing in the nitrification rate [26].

The use of immobilized microorganisms has been gaining importance in the last few decades because the activity of specific microorganisms can be enhanced to perform certain reactions; thus immobilized nitrifying cells in polymer pellets for enhanced nitrification can be used [27-29]. The immobilization of microorganisms in polymer resins is used in drug manufacturing and food processing, and using this technology for municipal wastewater treatment is being used in Japan [30,31]. The advantages of removing ammonia nitrogen from aqueous solutions using immobilized cells are: high cell concentration, long retention time of biomass in the system, rapid separation of cells from liquid ,and ability to scale up the process [32-34]. Immobilized cells can be divided in two categories, naturally attached cells (biofilms) and artificially immobilized cells [35-39]. The efficiency of the nitrification process can be enhanced by increasing the nitrifiers' retention time independent from the wastewater retention time [19]. The mechanism, of the immobilization process depends on providing suitable environment for the nitrifying microorganisms environment to perform at maximum rates. The nitrifiers are entrapped in 3 to 5 mm pellets made of polymers that are permeable to NH_3, oxygen, and carbon dioxide needed by these microorganisms; resulting in a fast and efficient removal of NH_3. Several gel-forming synthetic prepolymers have been mentioned in the literature. They generally form gels by polymerization or crosslinking [30,40]. Typical materials that can be used are polyethylene glycol (PEG) and polyvinyl alcohol (PVA). The

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successful application for nitrification treatment of municipal wastewater has been demonstrated using both natural polymers such as calcium alginate; and synthetic polymers such as glycol, PEG or polyvinyl alcohol, PVA [30,41,42,43]. Pellets made of synthetic polymers are superior to natural polymers in terms of strength and durability. It was found that their estimated life span is about 10 years. For this reason, synthetic polymer pellets are preferred for pilot and plant scale purposes. In this paper, nitrification using immobilized nitrifiers was examined in activated sludge system using PEG by upgrading an existing activated sludge system.

2 Methodology

To apply microorganism immobilization to wastewater treatment, the resin should have good durability to reduce operation and maintenance costs. Therefore, five types of synthetic resins were selected as a potential immobilizing material. These materials were polyethylene-glycol (PEG), acrylamide (AAm), epoxy (Epx), urethane, and melamine. PEG, AAm and Epx could gel well, while melamine resin did not gel well at ambient temperatures, and urethane resin could not be made into a spherical shape, though it gelled [40]. The physical characteristics and nitrifying activity of PEG, AAm and Epx pellets are shown in Table1. Nitrifying activity was measured as the respiration rate per unit volume of pellets in an aerated ammonia nitrogen solution (20 mg-N/l as NH_4C1). The results showed that there was no significant difference in physical characteristics between the three pellets. However, the nitrifying activities of the three kinds of pellets were significantly different. The change in respiration rate with time for PEG and AAm pellets are shown in Figure 1. The respiration rate of the PEG pellets increased quickly as compared to the AAm pellets. This indicates that PEG provides a more suitable

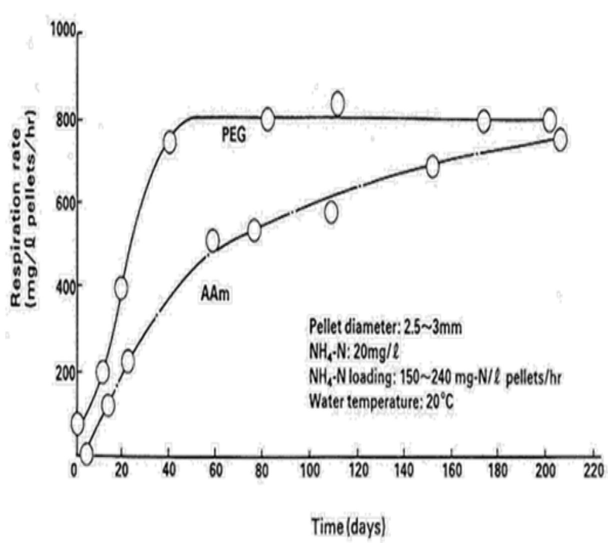

Fig. 1. Change in respiration rates with time for PEG and AAm pellets

TABLE 1
PHYSICAL CHARACTERISTICS AND RESPIRATION RATES OF PELLETS

	Acrylamide (AAm)	Epoxy (Epx)	Polyethylene-glycol(PEG)
Compressive Strength (kg/cm^2)	2.1	2.1 ~ 5.2	2.8 ~ 3.6
Deformation Ratio %	49	30 ~ 69	33 ~ 52
Durability	good	good	good
Initial Respiration Rate %	1 or less	1.8 - 3.3	5 - 15
Final respiration rate (mg-0_2/L-	550	180 ~ 500	850

environment for the growth of nitrifiers than AAm. Therefore, PEG was chosen as the resin for immobilizing nitrifiers.

The experimental works were carried out in Hitachi treatment plant. The immobilized nitrifiers in pellets were applied to the nitrified liquor recycling activated sludge system to investigate the ability of nitrifying pellets to remove ammonia in large influent loads. An aeration tank of volume 750 m^3 was converted for use in the immobilized nitrifiers' process. The system was divided into two tanks. The first tank (volume = 450 m^3)was used for the denitrification processes, while the second tank (Volume = 300 m^3)was used for nitrification process. A submerged agitator was installed in the denitrification part for mixing purposes. The wastewater from the denitrification tank was flowing into the nitrification tank through a channel that had inflow orifices at three positions in the bottom of the nitrification part. Air diffusion disks were installed in the bottom of the nitrification tank, to provide the oxyge required for the reaction, and to serve in mixing and agitating the nitrifying pellets and suspended sludge. The top of the nitrification tank was equipped with a wedge wire screen to retain the pellets in the nitrification tank. A portion of the mixed liquor emerging from this screen flowed into the final sedimentation tank, while the remaining portion was recycled to the denitrification tank passing through the nitrified liquor recycling channel. The volume of pellets added to the nitrification tank was 7.5% of the tank volume. Figure 2 shows a schematic diagram for the system. The design specifications and the effluent water qualities from primary settling tank are shown in Tables 2 and 3 respectively.

TABLE 2
DESIGN SPECIFICATIONS

Treatment Capacity = 2,250m³/day			
Bioreactor	**Total**	**Denitrification Tank**	**Nitrification Tank**
Volume	750m³	450m³	300m³
Size	5.5W x 5.0H x 29.0L	5.5W x 5.0H x 17.4L	5.5W x 5.0H x 11.6L
Retention Time	8hr	4.8hr	3.2hr
Pellet Dosing Rate = 7.5% (Pellet Volume / Nitrification Tank Volume)			
Final Settling Tank			
Volume	396m³		
Size	4.0m W x 3.0m H x 33.0m L		
Retention Time	4.2hr		

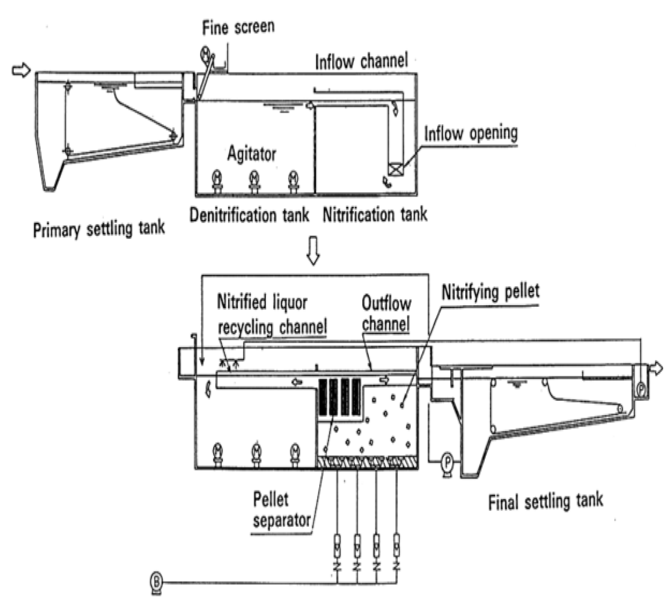

Fig. 2. Schematic diagram for the system

TABLE 3
EFFLUENT WATER QUALITY FROM PRIMARY SETTLING TANK

Water temperature (C°)	15.2	(10.0 – 17.0)
pH	7.0	(6.0 - 7.4)
BOD (mg/l)	69.5	(43.1 – 105)
S-BOD (mg/l)	35.5	(16.3 – 73.5)
COD (mg/l)	50.6	(37.7 – 64.7)
S-COD (mg/l)	32.8	(19.9 - 64.1)
SS (mg/l)	60.1	(17.0 – 84.0)
T-N (mg/l)	26.0	(14.0 – 37.0)
K_J –N (mg/l)	24.4	(14.0 – 36.0)
NH_4 –N (mg/l)	17.2	(9.5 – 27.0)
NO_3 –N (mg/l)	0.60	(0.15 – 2.80)
T-P (mg/l)	2.87	(1.60 – 3.80)
$P0_4$ –P (mg/l)	1.59	(0.59 – 2.61)

3 RESULTS AND DISCUSSION

At the beginning of the experimental works (during November and December), activated sludge and nitrifying pellets were introduced into the reaction tank, and acclimation operation was initiated. After that, three runs were performed. Figure 3 shows the changes in total nitrogen and ammonia nitrogen during the operation of the system. Influent T-N was 26 mg/l in average (range 14-37 mg/l), and influent ammonia nitrogen was 17.2 mg/l in average (range 9.5-27.0mg/l). The operating conditions of the immobilized nitrifiers process for run no.1 were a retention time of 8 hours, a recycling ratio of 3, mean mixed liquor suspended solids (MLSS) of 1,220 mg/l, and mean water temperature of 14.1C°. Biochemical Oxygen Demand (BOD_5) and Total Nitrogen (T-N) were found to be 66.1 mg/l and 25.7 mg/l respectively for the influent, and 3.7 mg/l and 6.6 mg/l respectively for the effluent, i.e., a BOD_5 removal efficiency of 94.4% and a T-N removal efficiency of 74.3%. The operating conditions of the Immobilized nitrifiers process for run no.2 were a retention time of 8 hours, a recycling ratio of 2 (including return sludge), mean MLSS of 1,740 mg/l, and mean water temperature of 15.0C°. BOD_5 and T-N were found to be 71.2 mg/l and 28.0 mg/l respectively for the influent, and 4.6 mg/l and 8.8 mg/l respectively for the effluent, i.e., a BOD_5 removal efficiency of 93.5% and a T-N removal efficiency of 68.6%. The operating conditions of the immobilized nitrifiers process for run no. 3 were a retention time of 6 hours, a recycling ratio of 3 (including return sludge), mean MLSS of 2,190 mg/l, and mean water temperature of 16.2C°. BOD_5 and T-N were found to be 70.3 mg/l and 23.9 mg/l re-

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spectively for the influent, and 3.8 mg/l and 6.8 mg/l respectively for the effluent, , i.e., a BOD_5 removal efficiency of 94.6% and a T-N removal efficiency of 71.5%. It is clear from the previous results that the removal efficiency of the total nitrogen increases with increasing the hydraulic retention time. This is due to the high generation time of the nitrifiers. Also, the efficiency of removal of total nitrogen increases with increasing the recycle ratio. This is because higher recycle ratio increases the activity of denitrifiers and so increase removal efficiency of T-N [44]. In each run, effluent T-N value obtained in the immobilized nitrifies process was almost half of that obtained from the conventional activated sludge process when compared to each other. In run no.3, T-N removal efficiency for the immobilized nitrifiers process was found to be 71.6%, while that for the conventional activated sludge process was found to be 34.7%, under same retention time. Except for a period during the middle of March when the dissolved oxygen level dropped to 2.5mg/l because of a defect in air diffusion control, ammonia nitrogen was approximately 98% nitrified, and the T-N removal efficiency (60% - 80%) was achieved.

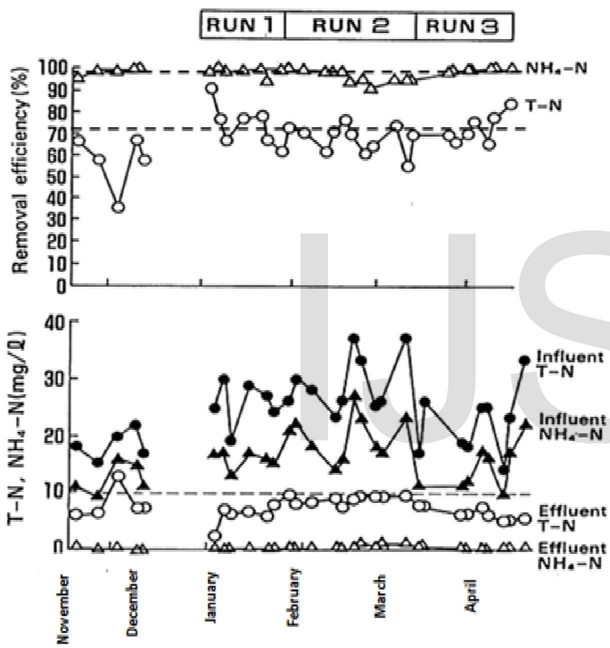

Fig. 3. Total nitrogen and ammonia nitrogen in influent and effluent

4 Conclusion

The conclusions obtained on upgrading of activated sludge system using immobilized nitrifiers in PEG resins are as follows;

1. PEG is the suitable material for immobilizing nitrifiers in terms of physical and biological characteristics, and the pellets with diameters (2 to 3) mm are fluidized sufficiently in a nitrification tank.
2. Recycling of nitrified liquor for denitrification can be accomplished by the airlift effect produced between nitrification and denitrification tanks without any additional energy.
3. PEG pellets can be utilized in nitrification tanks with activated sludge to increase nitrification capacity.
4. Even at lower temperatures, about 70% of influent total nitrogen was removed, and effluent BOD_5 was consistently maintained at less than 20mg/l.
5. The reactor volume required can be reduced to be half that for the conventional system, leading to reduction in the initial costs.

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