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Modelling transportation and transformation of nitrogen compounds at different influent concentrations in sewer pipe

T.Y. Pai [a,*], G.S. Shyu [b], L. Chen [c], H.M. Lo [d], D.H. Chang [d], W.J. Lai [d], P.Y. Yang [d,e], C.Y. Chen [f], Y.C. Liao [f], S.C. Tseng [d]

[a] Master Program of Environmental Education and Management, Department of Science Application and Dissemination, National Taichung University of Education, Taichung City 40306, Taiwan, ROC
[b] Department of Environmental Management, Tungnan University, Shenkeng, New Taipei City 222, Taiwan, ROC
[c] General Education Center, Shuzen College of Medicine and Management, Luju, Kaohsiung City 82144, Taiwan, ROC
[d] Department of Environmental Engineering and Management, Chaoyang University of Technology, Wufeng, Taichung City 41349, Taiwan, ROC
[e] Graduate Institute of Biochemical Science and Technology, Chaoyang University of Technology, Wufeng, Taichung City 41349, Taiwan, ROC
[f] Graduate Institute of Environmental Engineering, National Central University, Chungli 320, Taiwan, ROC

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ABSTRACT

A mathematical model was established to describe the transportation and transformation of nitrogen compounds in the sewer pipe. In order to verify the consistency between the experimental data and model simulation data, four runs of experiments were carried out in a 21 m long, 0.15 m diameter model sewer. The results showed a good consistency between the experimental and simulation values (all correlation coefficients >0.81). According to the good consistency, it was proved that the attached heterotrophic biofilm on the sewer bottom played a dominant role on degradation of compounds in the system. Readily biodegradable substrate (S_S) decreased with the test time due to aerobic and anoxic growth of heterotrophs. Ammonia and ammonium nitrogen (S_{NH}) increased with the test time. But nitrate and nitrite nitrogen (S_{NO}) and soluble organic nitrogen (S_{ND}) decreased. Dissolved oxygen (S_O) declined due to the microbial consumption and subsequently increased due to reaeration, forming a sag curve. Furthermore, the transformation pathways of different compounds were identified in this study.

1. Introduction

Many irrigating channels, drainage systems, and sewer systems receive different types of wastewater. The flow characteristics in these systems are shallow, and the bottoms are attached by a lot of biofilm. The qualities of the wastewater have complex compositions including carbon and nitrogen compounds with different oxidized states. Many previous studies have discussed the transformation of different compounds in natural channels, but the studies in sewers are less concerned. Because the sewer systems receive a large amount of wastewater from either industrial effluents or households with high concentrations, the transportation in sewer becomes more important.

Wastewater quality in sewer systems changed due to microbial processes during transportation [1]. The transformation of soluble and particulate compounds occurred in the bulk water and biofilm, respectively. The wastewater quality changed under either aerobic or anaerobic conditions which were determined by the dissolved oxygen (DO, S_O) concentrations. Many previous studies have investigated and quantified these microbial changes in wastewater substrate and in biomass [2–5].

* Corresponding author. Tel.: +886 4 22183541; fax: +886 4 22183540.
E-mail address: bai@ms6.hinet.net (T.Y. Pai).

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Hvitved-Jacobsen et al. [6,7] proposed a mathematical model which was based on the kinetics from the Activated Sludge Model (ASM) [8] to describe the microbial transformations under variations of aerobic and anaerobic conditions in sewer system.

Among all compounds, the interactions between the biofilm and the nitrogen compounds are very complicated due to the various kinds of nitrogen compounds and water flow conditions in sewers. In sewers, two species of autotrophic bacteria are capable of oxidizing ammonia to nitrite and subsequently to nitrate under aerobic condition. Once the nitrate is present in the sewage, it will serve as the electron acceptor of the heterotrophs under low DO condition. Then the nitrate nitrogen is converted to nitrogen gas by these denitrifying bacteria when DO depletes.

The concentrations of different nitrogen compounds in the domestic wastewater varied with variations of seasons, weather, and residents etc. Butler et al. [9] found that the concentrations of ammonia nitrogen ranged from 16 to 52 mg L^{-1}, the concentrations of nitrate nitrogen ranged from 0.48 to 1.16 mg L^{-1}. Jimenez and Landa [10] indicated that the averaged concentrations of total nitrogen and ammonia in the sewage were 33.16 and 29.43 mg L^{-1}, respectively. Seidl et al. [11] reported that the concentrations of ammonia and total Kjehldahl nitrogen (TKN) ranged from 19 to 35 mg L^{-1} and 28 to 59 mg L^{-1}, respectively. Arthur and Ashley [12] found that the averaged ammonia concentrations in sewage, near bed solids, and in deposited sediment were 18, 181 and 163 mg L^{-1}, respectively. Delgado et al. [13] reported that the concentrations of nitrate, nitrite and ammonia varied from 0.5, 0.3 and 39.2 mg L^{-1} to 0.4, 0.4 and 38.7 mg L^{-1}, respectively.

The transportation and transformation of nitrogen in sewer system are still not clear, but well understanding on the behaviors of nitrogen pollutants may result in the good operation of treatment plants and maintenance of sewer pipes. Therefore, the behaviors of these nitrogen compounds in the sewer systems are an important and worthwhile topic. With this point of view, it is better to understand the transformation processes in sewer more clearly, and the simulation technique is a good tool to achieve this goal. Since the transformation of nitrogen compounds were not described in previous models, the objectives of this study are listed as follows. (1) To establish a sewer model based on the kinetic of several models including ASM [8], Taiwan Extension Activated Sludge Model (TWEA) [14–22], and Hvitved-Jacobsen et al. [6,7] to describe the transformation of the nitrogen compounds including organic nitrogen, ammonia, nitrite, and nitrate nitrogen in sewer water phase and biofilm. (2) To explore the consistency between the experimental and simulation values of different compounds when initial dosing substrate concentrations varied. If the good consistency revealed, the major transformation pathway could be identified. (3) To analyze the kinetics of different components in the sewer by using the mathematical model.

Although the nitrogen transformation was included in previous activated models [8,18,20,21], it could not be applied in sewer pipe because the condition was different from that of wastewater treatment plant. Although the previous sewer models could be applied in sewer pipe [6,7], the nitrogen transformation was not included. Therefore the significant novelty between this sewer model and other cited models was described as follows. (1) Two types of microbial kinetics (heterotroph and autotroph) in sewer water phase and biofilm phase for wastewater quality transformation during transportation were taken into account in this sewer model. There are significant differences for microbial reactions between large river and shallow sewer. In large river, the microbes in bulk water column predominate over the reaction. While in sewer, the reaction was predominated by biofilm attached on the sewer bottom. The major advantage to consider separate variables of biofilm and bulk water was that the predominant microbial activities responsible for compound transformation could be evaluated. (2) The transformation of the nitrogen compounds including hydrolysis, ammonification, nitrification, and denitrification in sewer water phase and biofilm was considered in this sewer model. (3) This sewer model included reaeration which would result in the increase of DO concentration and affect the transformation of different nitrogen compounds indirectly.

2. Materials and methods

2.1. Experimental sewer

The experiments were conducted in a 21 m long, 0.15 m diameter model sewer and the material of the pipe was plastic, as shown in Fig. 1. The temperature of water was controlled at 28 centigrade. The slope and the flowrate in the pipe could be varied independently. A pump was installed to recirculate the water from the tail water tank to the head water tank. A DO meter was installed in the recirculation tank to measure the DO concentration. The head water tank, tail water tank and recirculate tank were sealed to prevent the water from being reaerated.

2.2. Description of experiments

The synthetic substrate was prepared with full-fat dry milk powder and other reagents. Also, its pH was adjusted to 7–7.5 with 1 N NaOH solution. It was used for the pilot scale process operation. Table 1 lists the major components of synthetic wastewater.

The system was seeded with activated sludge under steady influent flow. When effluent concentration was held constant, the biofilm was considered to be under a stable condition. Under this condition, biofilm had accumulated stably and grew in large colonies on the sewer bottom. Before and after each batch test, the biofilm was acclimated under steady condition again. The steady flow velocity was set at 0.6 m s^{-1} and the pH was maintained at 6.0–7.2. There were four experiment runs