

Nitrogen Removal Efficiency at Centralized Domestic Wastewater Treatment Plants in Bangkok, Thailand

Pongsak Noophan^a, Pongsri Paopuree^a, Kullaya Kanlayaras^b, Sanya Sirivithayapakorn^b and Somkiet Techkarnjanaruk^c

^a Department of Environmental Science, Faculty of Science, Silpakorn University, Nakhon-pathom Province, Thailand 73000

^b Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand 10900

^c National Center for Genetic Engineering and Biotechnology, King Mongkut's University of Technology Thonburi, Bangkok, Thailand 10140

Abstract

In this study, influents and effluents from centralized domestic wastewater treatment systems in Bangkok (Rattanakosin, Dindaeng, Chongnonsi, Nongkhaem, and Jatujak) were randomly collected in order to measure organic nitrogen plus ammonium-nitrogen (total Kjeldahl nitrogen), total organic carbon, total suspended solids, and total volatile suspended solids by using *Standard Methods for the Examination of Water and Wastewater 1998*. Characteristics of influent and effluent (primary data) of the centralized domestic wastewater treatment system from the Drainage and Sewerage Department of Bangkok Metropolitan Administration were used to analyze efficiency of systems. Fluorescent in situ hybridization (FISH) was used to identify specific nitrifying bacteria (ammonium oxidizing bacteria specific for *Nitrosomonas* spp. and nitrite oxidizing bacteria specific for *Nitrobacter* spp. and *Nitrospira* spp.). Although *Nitrosomonas* spp. and *Nitrobacter* spp. were found, *Nitrospira* spp. was most prevalent in the aeration tank of centralized wastewater treatment systems. Almost all of the centralized domestic wastewater treatment plants in Bangkok are designed for activated sludge type biological nutrient removal (BNR). However, low efficiency nitrogen removal was found at centralized wastewater treatment plants in Bangkok. Influent ratio of TOC:N at centralized treatment plant is less than 2.5. Centralized wastewater treatment systems have not always been used suitably and used successfully in some areas of Bangkok Thailand.

Keywords: nitrogen removal; centralized wastewater treatment plant; Bangkok; Thailand

1. Introduction

Centralized wastewater treatment systems (CWTs) have been the focus of the treatment efforts and are widely used. These systems, however, have not always been used successfully, such as in some areas in Bangkok. CWTs offer many advantages but may also cause problems, such as requiring large amounts of energy, chemicals, and money. They can also degrade water quality and threaten public health by the release of raw sewage into the environment by sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs). Collection systems of centralized wastewater treatment in Bangkok are a major source of CWTs and require a significant budget. Activated sludge type biological nutrient removal (BNR) treatment systems are popular and always designed for all centralized wastewater treatment plants for domestic wastewater in Bangkok, Thailand.

1.1. Conventional Wastewater Treatment Plants in Bangkok

Long-term planning in Bangkok calls for ten centralized wastewater treatment plants. The Drainage and Sewerage Department of Bangkok Metropolitan Administration is responsible for all wastewater management in Bangkok. For example, the Dindaeng and Jatujak Treatment Plants in Bangkok are designed as activated sludge with nitrogen and phosphorus removal: each plant operates in anoxic and aerobic conditions.

The Rattanakosin Treatment Plant is designed as a two-stage activated sludge. The Chongnonsi Treatment Plant uses a cyclic activated sludge system both of these specifically target nutrients. The Si Phraya Treatment Plant uses a contact stabilization activated sludge. The Nongkhaem and Thung Kru Treatment Plants employ an Envirex vertical Loop reactor because of many advantages,

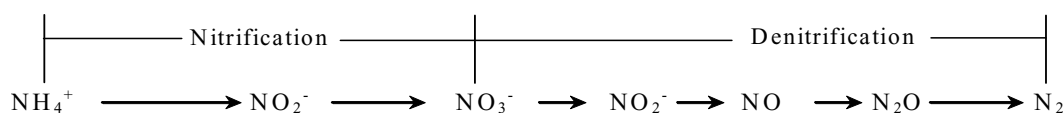


Figure 1. Overview of the Cycle in Biological Treatment of Nitrogenous Compounds in Wastewater

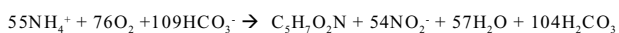
such as the capability to remove nutrients via an oxidation ditch in each reactor, low space requirements and low biosolids production (Metcalf and Eddy, 2003). However, there are disadvantages of the system including the energy required for aeration (Metcalf and Eddy, 2003). This type of system is also found in most developed countries (North America, Europe, Australia, and Japan).

1.2. The Conventional Approach for Nitrogen Removal

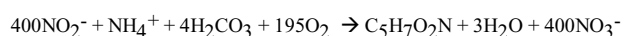
The conventional approach for nitrogen removal in wastewater involves a nitrification process ammonium, (NH_4^+) to nitrite (NO_2^-) on to nitrate (NO_3^-) followed by denitrification nitrate (NO_3^-) to nitrite (NO_2^-) to nitric oxide (NO) to nitrous oxide (N_2O) and then to nitrogen gas (N_2) end product, as depicted in Fig. 1. This process is widely used for the treatment of municipal and industrial wastewaters.

1.3. Nitrification

Nitrification is a two-step process performed by two different groups of microorganisms. These groups of microorganisms are autotrophic, utilizing CO_2 as the carbon source for biosynthesis and oxidation of nitrogen compounds as the energy source. The first reaction is ammonia oxidation. Ammonia-oxidizing bacteria oxidize ammonia to nitrite; this group of bacteria includes *Nitrosomonas* sp., *Nitrosococcus* sp., *Nitrospira* sp. and *Nitrosolobus* sp. The biological oxidation of ammonia to nitrite in the nitrification process is carried out by the following reaction:



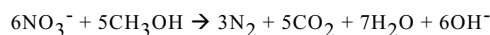
In the second reaction, nitrite oxidation, the nitrite is transformed to nitrate. Nitrite-oxidizing bacteria include *Nitrobacter* sp., *Nitrospira* sp., *Nitrococcus* sp., and *Nitrocystis* sp. Nitrite oxidation stoichiometry is shown below:



1.4. Denitrification

Denitrifying bacteria use organic compounds (glucose, ethanol, methanol, etc.) as a carbon source. These bacteria are heterotrophic. Furthermore, they

can grow faster than autotrophic bacteria (nitrification process) that use inorganic carbon (CO_2) as the carbon source (as a bacteria above). Nitrate and nitrite reducers use nitrate and nitrite as the terminal electron acceptor, respectively. Also, nitrate and nitrite reducing bacteria can act as facultative denitrifiers (both aerobic and anaerobic conditions). Bacteria in these groups include *Pseudomonas* sp. (*P. aeruginosa*, *P. fluorescens*, *P. denitrificans*), *Archromobacter* sp., *Alcaligenes* sp., *Bacillus* sp., *Hyphomicrobium* sp., *Rhodopseudomonas* sp., *Spirillum* sp., *Vibrio* sp. These genera have been found in general wastewater treatment plants (e.g. activated sludge, oxidation ditch, etc.). The biological reduction of nitrate to nitrogen gas in the denitrification process is carried out by the following reaction:



Both of these processes (nitrification and denitrification) are very well known and often used to remove nitrogen from municipal and industrial wastewaters. Bacteria in the nitrification step substantially consume oxygen and alkalinity, but bacteria in the denitrification step do not consume oxygen. However, these bacteria require biodegradable organic carbon. Generally, there is enough organic carbon in municipal wastewater for denitrifying bacteria.

In this study, efficiencies of nitrogen biological removal in the Bangkok centralized wastewater treatment plants were evaluated. Fluorescence in situ hybridization was used to confirm presence of nitrifying bacteria in the aeration tank of each centralized wastewater treatment plant in Bangkok.

2. Materials and Methods

Wastewater quality influent and effluent data from the centralized wastewater treatment plants (Si Phraya, Rattanakosin, Dindaeng, Chongnonsi, Nongkhaem, Thung Kru, and Jatujak) were obtained from the Drainage and Sewerage Department of Bangkok Metropolitan Administration to determine efficiencies of nutrient removal in each plant. Primary data were collected and analyzed as follows. Influent and effluent of water quality from the five selected (Rattanakosin, Dindaeng, Chongnonsi, Nongkhaem, and Jatujak) centralized wastewater treatment plants in Bangkok were

Table 1. Oligonucleotide probes used in this study.

Probe	Target	Sequence	Reference
EUB338	Most Bacteria	GCT GCC TCC CGT AGG AGT	Amann <i>et al.</i> (1995)
EUB338II	<i>Planctomycetales</i>	GCA GCC ACC CGT AGG TGT	Daims, <i>et al.</i> (1999)
NSM 156	<i>Nitrosomonas</i> spp.	TAT TAG CAC ATC TTT CGA T	Wagner <i>et al.</i> (1995)
NIT 3	<i>Nitrobacter</i> spp.	CCT GTG CTC CAT GCT CCG	Wagner <i>et al.</i> (1996)
NTSPA 714	<i>Nitrospira</i> spp.	CCT TCG CCA CCG GCC TTC	Loy <i>et al.</i> (2002)

collected and analyzed according to *Standard Methods for the Examination of Water and Wastewater 1998*. Samples from the Rattanakosin, Dindaeng, Chongnonsi, Nongkhaem, and Jatujak Treatment Plants were collected three times in the year of 2007. All samples were kept at 4 °C until analysis. Total suspended solids (TSS) and volatile suspended solids (VSS) were analyzed by Methods 2540 D and 2540 E, respectively. Organic nitrogen plus ammonium nitrogen (total Kjeldahl nitrogen, TKN) were analyzed by Methods 4500 N_{org} B (Macro-Kjeldahl) and 4500 NH₃ (Titrimetric), respectively. Total organic carbon (TOC) was analyzed by TOC Analyzer, Tekmar-Dohrman Phoenix 8000 (Tekmar-Dohrman, Ohio, USA.). Physical and chemical characteristics of centralized municipal wastewater, such as temperature, pH, and oxidation-reduction potential (ORP) were immediately measured in the field.

Fluorescent in situ hybridization (FISH) in this work followed the method of Amann (1995) and Daims *et al.* (1999). Samples from the five centralized domestic wastewater treatment plants were analyzed to identify aerobic ammonium oxidizing bacteria (AerAOB, e.g. *Nitrosomonas* spp.), aerobic nitrite oxidizing bacteria (AerNOB, e.g. *Nitrobacter* spp. and *Nitrospira* spp.), and anammox bacteria (*Planctomycetales*). These probes were commercially synthesized by Sigma-Aldrich (St. Louis, MO, USA). Oligonucleotide probes used in this investigation are listed in Table 1. Each sample was analyzed in triplicate. To quantify relative bacteria populations in this work, the digital image analysis program *daime* (version 1.1) was used (Daims *et al.*, 1999).

3. Results and Discussion

Physical and chemical characteristics of influent and effluent at the five selected centralized treatment plants (Dindaeng, Nongkhaem Chongnonsi, Jatujak, and Rattanakosin) were shown in Table 2. For all activated sludge plants in Bangkok, the design values for influent BOD, total nitrogen, and phosphorus are 150 mg/L, 20-30 mg N/L, and 6-8 mg P/L, respectively. However, measured values were significantly lower than the design values, as shown in Table 3, and 4.

Several factors may contribute to the low BOD in the influent to centralized wastewater treatment plant. First, each house in Bangkok has a primary treatment system (e.g. septic tank). Second, high wastewater temperatures may increase bacterial digestion in sewage pipes en route to the centralized wastewater treatment plant. Third, infiltration and inflow may dilute the sewage. Finally, wastewater composition may vary simply due to lifestyle (e.g. no garbage disposals, less flushed toilet paper).

The characteristics of influent and effluent from the five selected (Rattanakosin, Dindaeng, Chongnonsi, Nongkhaem, and Jatujak) were collected and analyzed in order to confirm the data of water quality from the Drainage and Sewerage Department of Bangkok Metropolitan. The results were not significantly different (data not show).

Low efficiencies of both nitrogen and phosphorus removal in the Bangkok's CWTs were found because influent ratios of TOC:N and BOD:P were extremely low. Theoretically, suitable TOC:N and BOD:P ratios for biological nutrient removal should be 3-5 (Sedlak, 1991) and 20-30 (Metcalf

Table 2. Characteristics of Influent and Effluent at the Five Selected Centralized Treatment Plants

Para-meter	Dindaeng		Nongkhaem		Chongnonsi		Jatujak		Rattanakosin	
	Inf*	Eff*	Inf*	Eff*	Inf*	Eff*	Inf*	Eff*	Inf*	Eff*
pH	6.92	6.92	6.30	6.63	7.25	7.05	7.14	6.98	7.04	6.93
Temp (°C)	28.4	28.7	30.7	30.5	29.6	29.9	31.1	33.8	31.6	31.7
ORP (mV)	-130	68	-48	86	-35	93	-130	54	-248	221
TSS (mg/L)	35.9	8.6	38.5	9.0	39	7.4	46.3	15.3	85.3	9.7
VSS (mg/L)	24.7	6.7	28.5	7.5	28.5	6	37.5	8.5	40.7	9
TOC (mg/L)	10.3	7.5	9.0	3.4	22.7	10.4	22.3	8.1	8.3	5.2

Samples from each plant were collected three times in the year of 2007. *Average data

Table 3. The BOD, Ammonia (NH₃), and total Kjeldahl nitrogen (TKN) values of Influent and Effluent at the Centralized Treatment Plants

	BOD _{inf} * (mg/L) in 2007	BOD _{eff} * (mg/L) in 2007	NH ₃ (inf)* (mg/L) in 2007	NH ₃ (eff)* (mg/L) in 2007	TKN _{inf} (mg/L) in 2007	TKN _{eff} (mg/L) in 2007
Si Phraya	54.22±1.84	5.35±0.31	no data	no data	10.63±6.01	2.43±1.66
Rattanakosin	56.98±8.21	13.54±2.19	6.56±0.67	2.90±0.07	8.48±0.77	4.51±1.15
Dindaeng	31.26±2.88	3.76±0.79	10.53±1.63	0.24±0.17	no data	no data
Chongnonsi	33.79±12.95	6.47±1.87	8.51±1.24	1.31±0.61	9.58±0.86	1.93±0.49
Nongkhaem	32.78±7.19	3.81±1.14	7.13±1.23	0.43±0.27	10.95±1.75	1.53±0.29
Thung Kru	37.28±5.65	4.84±1.48	8.27±1.43	0.51±0.32	12.47±1.61	2.63±0.37
Jatujak	36.42±6.69	11.73±1.50	6.69±1.70	2.29±0.48	10.23±2.38	6.58±0.93

Average (± S.D.) * data all year long in 2007 from the Drainage and Sewerage Department of Bangkok Metropolitan

and Eddy, 2003), respectively. Influent ratios of TOC:N and BOD:P in Bangkok centralized wastewater treatment plant are 0.73-2.21 and 13-22, respectively. Thus, nutrient removal by biological treatment was ineffective because influents to CWTs in Bangkok have very low BOD and TOC with relatively high nitrogen and phosphorus. However, these CWTs are able to nitrify ammonium to nitrate. An external carbon source is likely necessary to achieve denitrification in these centralized wastewater treatment plants. However, carbon addition can be very expensive for high volumes of wastewater or high concentrations of nitrogen. Various external carbon sources are suggested in the literature such as food factory wastewaters (brewery waste, fruit juice, and molasses) (Henze and Harremoës, 1978). Further research should investigate the addition (methanol, ethanol, sugar) or an external carbon source from food factories, such as by-products (molasses) for denitrification process in the Bangkok centralized treatment plants.

Fluorescence in situ hybridization (FISH) applied to five sludge of the centralized treatment plants confirmed that nitrifying bacteria

(*Nitrosomonas* spp. *Nitrobacter* spp., and *Nitrospira* spp.) were present in each aeration tank. The sludge from five selected treatment plants in the aeration tank responded to the probes NSM 156 (ammonium oxidizer bacteria) and NIT 3 (nitrite oxidizer bacteria), indicating *Nitrosomonas* spp. and *Nitrobacter* spp., respectively. However, the five selected sludge responded strongly to the probes NTSPA 714, indicating that the most prevalent species of nitrite oxidizer bacteria was *Nitrospira* spp. Because *Nitrospira* spp. is unable to grow heterotrophically while *Nitrobacteria* spp. can grow heterotrophically (Ehrlich *et al.*, 1995; Daims *et al.*, 2001), one might conclude that there is insufficient organic carbon in the aeration tanks of the Bangkok treatment plants. This result could show that there were significantly low oxygen and nitrite concentrations in an aeration tank of five selected treatment plants. This result confirmed Daims *et al.* (2001) experiment that nitrite oxidizer bacteria (*Nitrospira* spp.) were able to grow in aerated bioreactor with lower nitrite and oxygen concentrations and nitrify nitrite by using nitrite as an electron donor and oxygen as an electron acceptor.

Table 4. Nitrogen and Phosphorus Removal Efficiency at the Centralized Treatment Plants

Name of Treatment Plant	Influent		Effluent		Nitrogen Removal Efficiency	Phosphorus Removal Efficiency
	TN* (mg N/L)	TP* (mg P/L)	TN* (mg N/L)	TP* (mg P/L)		
Si Phraya	12.45±5.87	1.81±0.56	11.46±2.55	1.54±0.58	8.0%	14.9%
Rattanakosin	8.72±0.9	2.64±1.16	7.57±0.85	1.63±0.66	13.2%	38.3%
Dindaeng	12.11±1.49	2.31±0.17	8.54±0.62	1.51±0.29	29.5%	34.6%
Chongnonsi	10.23±1.05	2.48±0.93	6.6±0.93	1.49±0.18	35.7%	44.3%
Nongkhaem	11.76±1.47	1.74±0.26	6.68±0.78	0.89±0.11	43.2%	48.8%
Thung Kru	12.56±1.59	1.42±0.33	8.12±0.34	0.62±0.16	35.4%	56.3%
Jatujak	11.38±2.05	1.88±0.26	7.11±0.78	1.42±0.19	37.5%	24.5%

Average (± S.D.) * data all year long in 2007 from the Drainage and Sewerage Department of Bangkok Metropolitan

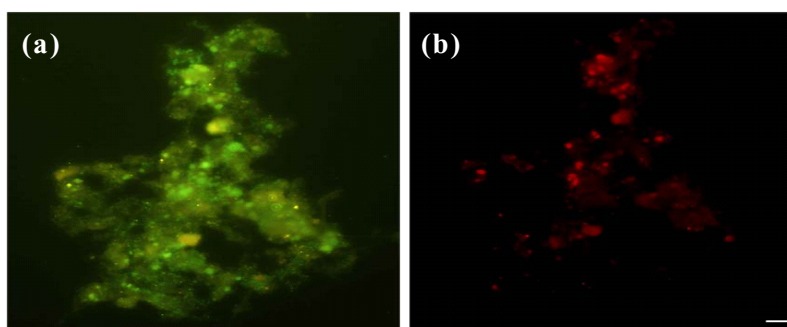


Figure 2. Fluorescent in-situ hybridization image of an aggregate from Nongkaem sludge, stained with (a) probe EUB338 (most bacteria) and (b) probe NSM 156 (*Nitrosomonas* spp.) (scale = 10 μ m)

The FISH images of an aggregate from Nongkhaem sludge with probes EUB (most bacteria) and NSM 156 (*Nitrosomonas* spp.) are shown in Figs. 2(a-b).

The Nongkhaem wastewater facility is the largest in the area. Only at this plant was a group of *Planctomycetales* detected by probe EUB338II but in very low number. It is postulated that anammox bacteria (ANAerobic AMMonium OXidation, anammox) may be presented in the Nongkhaem treatment plant. Strous *et al.* (1999) reported that *Planctomycetales* is a major group of anammox bacteria. The anammox process represents a potentially new approach for biological nitrogen removal one that bypasses the formation of NO_3^- and convert NO_2^- to N_2 gas with NH_4^+ as the electron donor and NO_2^- as the electron acceptor under anoxic conditions. The approach is extremely suitable to wastewater that has low BOD but high nitrogen such as domestic wastewater in Bangkok. However, fundamental information about this process is still unavailable and is greatly needed for implementation at larger scales.

Based on primary data from Drainage and Sewerage Department of Bangkok Metropolitan Administration, only 50% of domestic in Bangkok is routed to centralized wastewater treatment plants. The average flow of domestic wastewater treatment in Bangkok is more than 3×10^6 m^3/day (Drainage and Sewerage, Bangkok Metropolitan Administration, 2007). The remaining domestic wastewater in Bangkok has been treated by septic tank without filtration phase (decentralized or onsite treatment). In general, conventional onsite treatment of households requires septic tank followed by soil filtration. The second part (the filtration unit) is very important for treating effluent from a septic tank. But most houses in Bangkok do not have space for this treatment. Septic tanks alone cannot completely remove BOD, nutrients such as N and P, fecal coliforms, and *Escherichia coli*. Theoretically, septic systems are able to remove about 40-50%

of organic matter and BOD (Crites and Tchobanoglous, 1998; U.S. EPA, 2002). This significant flow of effluent from septic tanks ($\sim 1.5 \times 10^6$ m^3/day) could have a major impact on the Chao Phraya River in Bangkok. Based on data from Department of Thai Pollution Control and Industry Control, municipal wastewater is a major source of N and P in Thailand (Noophan *et al.*, 2007). The serious problem of the seven centralized wastewater treatment plants in Bangkok is that BOD influents to wastewater treatment plants are lower than design criteria (3-5 times). For this reason, these systems could significantly consume an enormous amount of energy, chemicals, and money but could not remove both nitrogen and phosphorus. These large centralized wastewater treatment plants cannot significantly decrease the water pollution problem in some areas of Bangkok.

Although Bangkok Metropolitan Administration invests greatly in order to improve water quality in many canals and the Chao Phraya River, water quality in these canals and the Chao Phraya River is still impaired. It is time to consider that construction of huge centralized wastewater treatment plants cannot always solve water pollution in Bangkok. Distributed (onsite or clustered) treatment systems, with proper management have demonstrated good performance (Crites and Tchobanoglous, 1998; U.S. EPA, 2002). All domestic wastewaters in Bangkok should be treated before discharge to the environment, and both centralized and decentralized treatment can play a significantly role.

4. Conclusion

Influent BOD and TOC from the centralized treatment plants in Bangkok were about 3-4 times lower than design criteria. Influent ratios of TOC:N and BOD:P of centralized wastewater treatment plants at Bangkok are 0.73-2.21 and 13-22, respectively. Biological nitrogen removal could not occur

in these centralized treatment plants because there is insufficient organic carbon for denitrifying microorganisms; denitrification in these plants would likely require an external carbon source for denitrifying bacteria. Also, more extensive sewage piping networks in Bangkok are reconsidered to efficiently route more domestic wastewater to centralized treatment plants for nutrient removal.

Acknowledgements

The authors are appreciative for a grant from the Faculty of Science, Silpakorn University, Nakhon-pathom Province and Faculty of Engineering, Kasetsart University, Bangkok. The authors would like to thank Department of Environmental Science, Silpakorn University, Department of Environmental Engineering, Kasetsart University, and National Center for Genetic Engineering and Biotechnology, King Mongkut's University of Technology Thonburi for good support of this project.

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Received 19 December 2008

Accepted 10 January 2009

Correspondence to

Dr. Pongsak Noophan
Department of Environmental Science,
Faculty of Science,
Silpakorn University,
Nakhon-pathom Province, 73000
Thailand
Tel: 034-219-146 ext 2861
Fax: 034-273-047
Email: pongsak@su.ac.th