A Study of Nitrogen and Phosphorus in Various Wastewaters in Thailand

การศึกษาปริมาณของไนโตรเจนและฟอสฟอรัสในน้ำเสียที่หลากหลายในประเทศไทย

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Abstract

To avoid harmful effects on human health and environment, nitrogen (N) and phosphorus (P) must be removed from wastewater before discharge into the environment. Nitrate (NO_3^-) is a significant potential public health hazard in drinking water and presents the risk of methemoglobinemia (blue baby syndrome) in infants. Nitrogen and phosphorus are major nutrients that enhance eutrophication of freshwater, lakes, estuaries, and oceans. Domestic sewage, agriculture, and industries are sources of N and P, but domestic sewage is a major source of these nutrients in Thailand. In order to control excessive discharge of both N and P substrates, high efficiency treatment systems and good management practices have been developed and are proposed in this study. Effluents from stabilization ponds (centralized wastewater treatment plants) were randomly sampled and analyzed according to Standard Methods 2000 all year long in 2001 and 2005. The characteristics of effluent (both N and P) from many different wastewater sources were determined and analyzed by using primary data from the Department of Pollution Control and Industry Control. Low efficiencies of nutrient removal by biological treatment in both centralized and decentralized wastewater treatment plants were found. For this reason, excessive quantities of both N and P substrates should not be discharged directly to the environment. The best way to remove both N and P is by a combination of biological and chemical treatment. Materials to effectively adsorb phosphorus while providing growth medium for nitrogen removing bacteria would be discussed. The results from this study could be used as a guideline for nutrient removal from municipal wastewater.

Keywords: nitrogen, phosphorus, absorbent
คำสำคัญ: ไนโตรเจน ฟอสฟอรัส สารที่สามารถดูดซับได้

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บทคัดย่อ

สารไนโตรเจนและฟอสฟอรัสในน้ำเสียควรต้องมีการกำจัดก่อนปล่อยออกทิ้งสู่สิ่งแวดล้อม โดยเฉพาะไนโตรเจนในฟอร์มของไนเตรท สามารถทำให้เกิดโรค methemoglobinemia หรือ blue baby syndrome ในเด็กทารก ไนโตรเจนและฟอสฟอรัส คือธาตุอาหารหลักที่ทำให้เกิดยูโทรฟิเคชั่น (eutrophication) ในแหล่งน้ำต่าง ๆ เช่น แหล่งน้ำจืด ทะเลสาบ ปากแม่น้ำ และทะเล แหล่งที่มาของไนโตรเจนและฟอสฟอรัสในน้ำเสียมาจากน้ำทิ้งชุมชน เกษตรกรรม และอุตสาหกรรม แต่แหล่งที่มาที่ใหญ่ที่สุดมาจากน้ำทิ้งชุมชน การศึกษาวิจัยนี้มีการพัฒนาและแนะนำระบบบำบัดไนโตรเจนและฟอสฟอรัสรวมถึงการจัดการที่มีประสิทธิภาพสูง มีการตรวจวิเคราะห์ปริมาณของไนโตรเจนและฟอสฟอรัสในตัวอย่างของน้ำที่ผ่านการบำบัดจากระบบบ่อผันสภาพ (stabilization pond) ซึ่งเป็นระบบบำบัดน้ำเสียรวมของเมือง โดยใช้วิธีวิเคราะห์ตามวิธีมาตรฐานทั่วไป การวิเคราะห์ตัวอย่างเป็นการสุ่มตรวจ รวมไปถึงการใช้ข้อมูลดิบจากกรมควบคุมมลพิษและกรมโรงงานย้อนหลังเป็นเวลา 5 ปี ตั้งแต่ปี 2544 ถึง 2548 ผลการวิเคราะห์ตัวอย่างน้ำที่ผ่านการบำบัดจากระบบบำบัดน้ำเสียรวมของเมืองส่วนใหญ่ พบว่าไม่สามารถบำบัดทั้งไนโตรเจนและฟอสฟอรัสได้ และน้ำที่ผ่านการบำบัดเหล่านี้ไม่ควรปล่อยออกสู่สิ่งแวดล้อมโดยตรง ควรมีการบำบัดเพิ่มโดยใช้สารที่สามารถดูดซับฟอสฟอรัสได้ วิธีที่ดีที่สุดในการบำบัดทั้งไนโตรเจนและฟอสฟอรัส คือการใช้ทั้งวิธีทางเคมีและชีวภาพ สารที่สามารถดูดซับฟอสฟอรัสได้มีการกล่าวถึงในการศึกษานี้ ผลงานวิจัยนี้สามารถใช้เป็นแนวปฏิบัติในการบำบัดทั้งไนโตรเจนและฟอสฟอรัสในน้ำทิ้งชุมชน

Introduction

Nitrogen (N) and phosphorus (P) must be removed from wastewater before they are discharged into the environment in order to preclude harmful effects on human health and the environment. Nitrate (NO_3^-) is a significant potential public health hazard in drinking water and presents the risk of methemoglobinemia (blue baby syndrome) in infants (Johnson and Kross, 1990). Nitrogen and phosphorus are major nutrients that enhance eutrophication of freshwater, lakes, estuaries, and oceans (Sedlak, 1991). However, both N and P removal from wastewater are still new pollutant issues in Thailand. Typical nitrogen and phosphorus concen trations of Thailand are higher than those of Australia, Japan, and United States of American. In the past, there was little concern about water quality and quantity because there were few people and many water resources. Currently, there is a large population and the water can be significantly deleterious. Many water resources cannot be used for water supply and aquatic life. Because of this important environmental problem, the Thai government is investing heavily in research and major projects.

Nitrogen and phosphorus substrates are from domestic sewage, agriculture, and industries. Figure 1 shows different sources of nitrogen and phosphorus in Thailand. Sources of nitrogen and phosphorus are from municipal sewage, agriculture, and industries. Domestic sewage and industries are point sources, but agriculture is a non-point source. In order to control excessive discharge of both N and P substrates, high efficiency treatment systems and good management practices have been developed and proposed. Although the conventional removal of nitrogen from wastewater by biological processes involving nitrification (NH_4^+ to NO_2^- to NO_3^-) followed by denitrification (NO_3^- to NO_2^- to N_2) is well known and possible biological treatment, the Sharon/Anammox process (NH_4^+ to NO_2^- to N_2) is challenging and needs more research for implementation in the field. Adsorption or precipitation with biological treatment is suitable for phosphorus removal. This work strives to find a suitable management and an appropriate treatment of municipal wastewater (point source) in order to remove both N and P by a combination of biological and chemical treatments. Such a treatment method would require low initial investment, inexpensive operation and minimal maintenance cost. Materials to effectively adsorb phosphorus while providing growth medium for nitrogen removing bacteria are discussed. The characteristics of effluent (both N and P) from many different wastewater sources were determined and analyzed by using primary data from the Department of Pollution Control and Industry Control. Furthermore, the characteristics of domestic wastewater from stabilization ponds were studied in order to confirm data from the Department of Pollution Control.

Material and Methods

1. *Collect and analyze for wastewater quality from different sources of wastewater treatment plants around Thailand.*

Wastewater quality effluent data (both nitrogen and phosphorus) from many different wastewater treatment plants from the Department of Pollution Control and Industry Control were used to determine efficiencies of N and P removal in each plant. Primary data was collected and analyzed all year long from 2001 and 2005. The analyzed data was described in domestic, agricultural, and industrial wastewater sections. The efficiencies of wastewater treatment plants both in Bangkok and other parts of Thailand (north, east, west, and south) are described in the domestic section.

2. *Study the characteristics of domestic wastewater from stabilization ponds*

All effluents from stabilization ponds from Khon Kaen province (Khon Kaen University) and the area of central Thailand (such as Ratchaburi, Phetchaburi, Kanchanaburi, and Prachuap Khiri Khan provinces) were sampled and analyzed according to Standard Methods 2000 all year long from 2001 to 2005. Samples from Khon Kaen province were collected four times (summer, two rainy seasons, and winter season), but samples from central Thailand was collected only once. Measured parameters in this work, including total alkalinity, total acidity, total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), chemical oxygen demand (COD), biological oxygen demand (BOD), ammonia (NH_3), total Kjeldahl nitrogen (TKN), nitrate (NO_3^-), orthophosphate and total phosphate (TP) were analyzed at the Department of Environmental Science, Faculty of Science, Silpakorn University, Nakhon Pathom province. All samples were kept under 4 ^{o}C until analysis. The physical and chemical characteristics of municipal wastewater, such as temperature, pH, and conductivity were immediately measured in the field. Filtrated and un-filtrated effluent samples were analyzed for TP parameter in order to compare samples with algae and without algae.

Results and Discussion

Collect and analyze for wastewater quality from different sources of wastewater treatment plants in Thailand

Domestic Wastewater

Primary data from Department of Pollution Control and Industry Control between 2001 and 2005 was analyzed in order to determine efficiencies of nitrogen and phosphorus removal for wastewater treatment plants in Thailand. The data show that a major source of both nitrogen and phosphorus in Thailand is from municipal wastewater. Currently, the Thai population is 64 million people (32% urban and 68% rural). Each house uses a septic tank for domestic sewage disposal. This system is able to remove organic matter (biological oxygen demand (BOD) or chemical oxygen demand (COD)) by about 40-50%, but septic tanks cannot completely remove N and P substrates (Katers and Zanoni, 1998). For this reason, effluent from septic tanks needs nutrients removal before direct discharge to the environment.

Based on primary data from the Department of Pollution Control, only 10% of domestic wastewater in Bangkok is routed to a centralized wastewater treatment plant for N and P treatment. The average flow of domestic wastewater through centralized wastewater treatment plants in Bangkok and through other wastewater treatment plants in various provinces is 500,000 m^3/day and 460,000 m^3/day, respectively. Most of the domestic wastewater treatment plants in Bangkok are activated sludge. Other provinces employ a stabilization pond consisting of anaerobic, facultative, and oxidation ponds. In cities with many tourists, such as Phuket, Chiang Mai and Chonburi (Pattaya) wastewater treatment plants may use activated sludge (AS), aerated lagoon (AL), and rotating biological contactors (RBC).

Normally, domestic wastewater in Thailand contains an average of 19-35 mg N/L and 1.3-10 mg P/L. Influents to wastewater treatment plants have 10-15 mg N/L and 1.3-5 mg P/L. All these values are lower than design criteria for nitrogen concentration and phosphorus concentration, 30 mg N/L, and 8 mg P/L, respectively. Removal of N and P is difficult because the influent ratios between COD and nitrogen and between BOD and P are very low. Theoretically, Sedlak, (1991) and Metcalf and Eddy, (2003) calculated that the suitable COD:N and BOD:P ratios for biological nutrient removal should be 5-8 and 20-30, respectively. Influent ratios of COD:N and BOD:P in centralized wastewater treatment plant at Bangkok are 3.2 and 5, respectively. For this reason, it is quite difficult to remove both P and N by using biological treatment. From 2001 to 2005 , it is shown that the efficiencies of both P and N removal were 18-66% and 9-79%, respectively. Stabilization ponds and oxidation ponds of centralized wastewater treatment plants of different provinces in Thailand are not designed to treat these nutrients. The problem of the centralized wastewater treatment plant in Bangkok using biological treatment is that the COD:N and BOD:P ratios are not suitable. The nitrification process is able to proceed in a wastewater treatment plant, but the denitrification process is inhibited because there is insufficient carbon. An external carbon source is necessary in most municipal wastewater treatment plants in Thailand.

Long-term plans call for ten centralized wastewater treatment plants in Bangkok. So far, only six plants have been built and begun operations. The other four plants are under construction. Only one plant in Bangkok is specifically designed for phosphorus removal using chemical treatment (precipitation with alum and polymer). However, this chemical system is not frequently used because of very high operating and reagent costs. The effluent standards for nitrogen and phosphorus in Bangkok are less than 10 mg N/L and 2 mg P/L. The phosphorus standard is met in only some areas of Bangkok. Nitrogen and phosphorus loading from municipal wastewater is 570 ton/day and 101 ton/day, respectively (primary data from Department of Pollution Control from 2001 to 2005 were used to produce these values). The calculated nitrogen and phosphorus content in the effluent from the centralized plant are 15 ton N/day and 2.4 ton P/day (primary data from Department of Pollution Control from 2001 to 2005 were used to produce these values). The Thai government is investing heavily to build huge centralized wastewater treatment plants in Bangkok and other provinces in Thailand, but these plants cannot significantly remove nutrients. Interestingly, the domestic wastewater treatment plants are capable of handling greater organic loading. Currently, only 15-30% of the total wastewater is introduced into the plants. The most practical solution for treating domestic wastewater is to route more municipal wastewater to those plants adding external carbon sources for the denitrification process. Although funding is an issue, there is a need to construct a more thorough network of sewage pipes from different zones in each city. Another possible solution could be the development of decentralized treatment to handle discharge from individual septic tanks. This issue is discussed in more detail in the discussion section about domestic wastewater from stabilization ponds.

Agricultural Wastewater

Agriculture wastewater contains N and P nutrients too, but in quantities less than that of domestic wastewater. Major agricultural wastewater sources include animal wastes (pig, poultry, fish and shrimp) and fertilizers. Poultry farm discharges are different to control because there are both open and closed edges. Fertilizer from growing plants often drains both nitrogen and phosphorus to rivers and lakes. On average about 10% of fertilizer is drained to a public water resource. Quantities of nitrogen and phosphorus from different agricultural wastewater sources are shown in Table 1. All these agriculture sources drain many nutrients to public water resources. It is difficult to control agricultural wastewater in Thailand because it is primarily a non-point source. Additionally, agriculture is very widespread being the principal livelihood for the population.

Industrial Wastewater

Before significant environmental studies most people believed that industry was the major source of N and P in Thai freshwater lakes, estuaries and the ocean. However, the analysis of the data from the Department of Pollution Control and Industry Control shows that the primary source of N and P is from municipal wastewater. In Thailand, the major industrial wastewater sources of N and P are fish canning, chicken processing, and pig slaughterhouses. Quantities of nitrogen and phosphorus from different industrial wastewater sources are shown in Table 2.

Study the characteristics of domestic wastewater from stabilization ponds

Low efficiencies of nutrient removal from domestic wastewater by biological treatment in stabilization ponds were found. Influent and effluent data of stabilization ponds from Khon Kaen province and the central Thailand area (such as Ratchaburi, Phetchaburi, Kanchanaburi, and Prachuap Khiri Khan provinces) are shown in Tables 3 and 4, respectively.

Although the BOD levels of the effluents from stabilization ponds are lower than the standard effluent of Thailand (20 mg/L), both nitrogen and phosphorus concentrations are significantly high. Stabilization ponds currently in use do not adequately decrease both nitrogen and phosphorus concentrations. The excessive N and P from stabilization ponds should not be discharged directly to the environment. TKN (organic nitrogen and ammonium nitrogen) can increase the BOD value or decrease the DO value in water resources and phosphorus is a major nutrient that enhances eutrophication. However, the regulation of effluent nutrient standards in Thailand for nitrate and phosphorus are 10 mg N/L and 2 mg P/L, respectively. These standards are applied to only some areas in Bangkok. The phosphorus standard is about 10 times higher than the standards of Australia and United States of America. Environmental scientists need to develop a suitable standard for individual effluents, domestic, industrial, and agricultural wastewaters in Thailand. A possible solution for increasing the efficiency of phosphorus removal in stabilization ponds is by adding other treatments at the end of stabilization ponds, such as wetland or a high efficiency phosphorus adsorption unit. It would be beneficial to find a material which would effectively adsorb phosphorus while providing growth medium for nitrogen-removing bacteria. Based on the literature review, Zhu et al. (1997) reported that Utelite from Utah, U.S.A could adsorb P at 3.46 g P/Kg. Sakadevan and Bavor (1998), moreover, showed that blast furnace slag from Australian Steel Mills Limited could adsorb P at 44.2 g P/Kg. Jenssen, et al. (1991) reported that Leca from Sweden had an adsorption capacity of 1.62 g P/Kg. Ex-un et al. (in prep.) determined that natural zeolite from Thailand could adsorb P at 0.10 g P/Kg. These four substrates provide very high P adsorption capacity. It is likely that P adsorption units could be applied to domestic sewage from septic tanks too. As we know, disposal of domestic sewage in each house uses a septic tank but this system cannot be used to treat both P and N substrates. Improving the removal of both organic matter and nutrients from decentralized wastewater (onsite treatment) is very important and urgent. However, any new methods (water reuse and recycling for agriculture or some industries) should have low operational and maintenance costs if they are to be applied in rural areas in Thailand. The best way to remove both N and P is by combination of biological and chemical treatments. Material to highly adsorb phosphorus while providing a growth medium for nitrogen removing bacteria should be determined for use in the field.

Conclusion

In Thailand, a major source of both nitrogen and phosphorus is from municipal wastewater. Centralized wastewater treatment plants in Thailand do not significantly remove both nitrogen and phosphorus. Furthermore, septic tank treatment from each house (decentralization treatment) does not remove both nitrogen and phosphorus. Applications of highly phosphorus adsorbing materials which provide growth medium for nitrogen-removing bacteria to effluents from stabilization pond and domestic sewage in septic tanks have been proposed. More extensive sewage piping networks are needed in cities to efficiently route more domestic wastewater to centralized treatment plants for nutrient removal.

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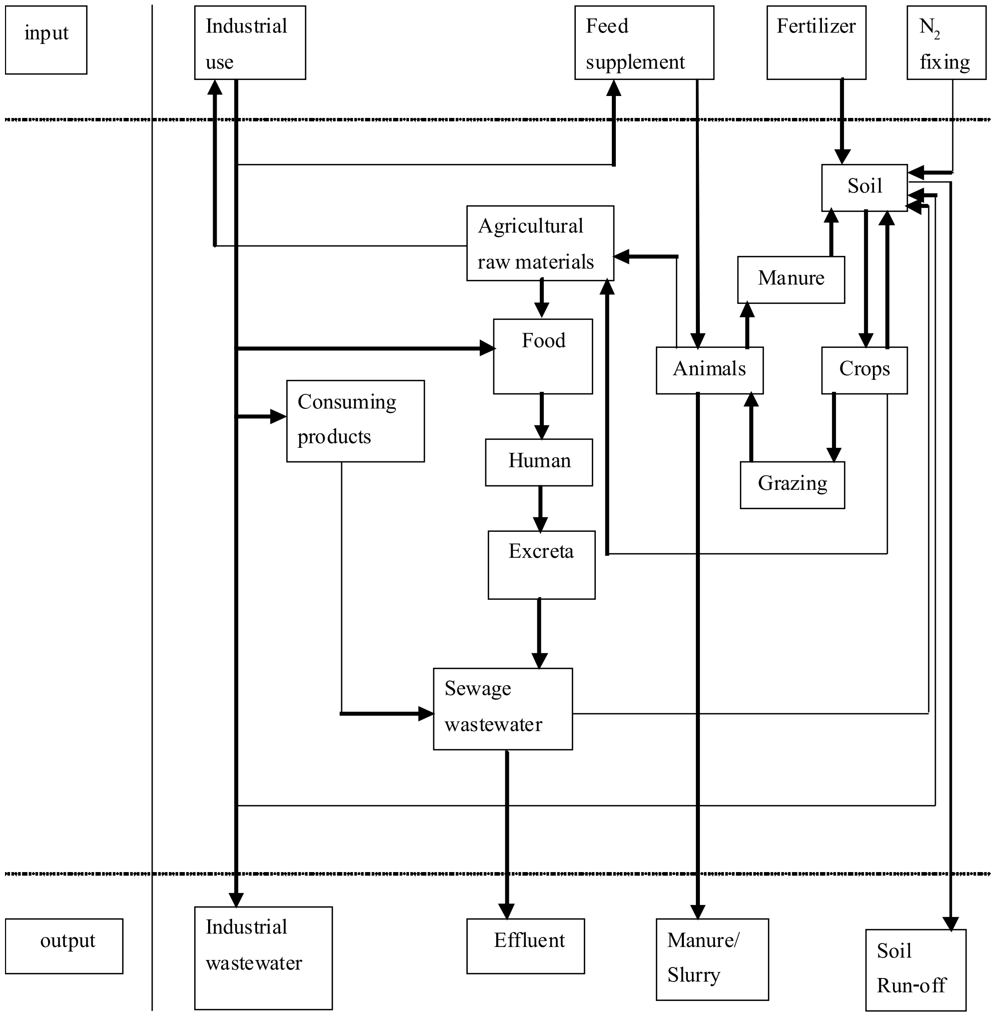

Figure 1. Sources of Nitrogen and Phosphorus of Thailand.

Table 1. Quantities of Nitrogen and Phosphorus from Different Agricultural Wastewaters.

Type of Agriculture	Nitrogen Ton/day	TKN Conc. (mg N/L)	Phosphorus Ton/day	Phosphorus (mg P/L)
Pig Farm	23	493	0.5	11.5
Shrimp Farm	21	0.08-1.46	2.1	0.04-0.06
Fish Farm	7	10	0.4	0.5
Fishery gate	15	502	1.5	50
Horticulture	117	2	11	0.2
Sum	183	-	15	-

Primary data from the Department of Pollution Control and Industry Control, from 2001 to 2005 were used to produce these values

Table 2. Quantities of Nitrogen and Phosphorus from Different Industrial Wastewaters.

Type of Factory	Nitrogen Ton/day	TKN Conc. (mg N/L)	Phosphorus Ton/day	Phosphorus (mg P/L)
Fish Canning	10	933	2.9	261
Chicken Processing	4	345	No data	No data
Pig Slaughterhouse	4	300-600	No data	No data
Sum	18	-	No data	No data

Primary data from the Department of Pollution Control and Industry Control from 2001 to 2005 were used to produce these values

Table 3. Influent and Effluent Data of Stabilization Pond from Khon Kaen Province.

Parameter and Unit	Influent	Effluent
pH	7.2-7.9	9.2-10.3
Temperature (°C)	27-29	27-29
Conductivity (μS/m)	515-762	350-476
Total Alkalinity (mg/L as $CaCO_3$)	25-218	0-128
Total Acidity (mg/L)	14-28	0-8
COD (mg/L)	129-267	64-102
BOD_5 (mg/L)	119-162	7.4-21
Total Solids (mg/L)	352-610	300-440
Total Suspended Solids (mg/L)	88-117	20-57
Total Dissolved Solids (mg/L)	252-491	271-372
Ammonia (mg N/L)	20-33	0.35-0.56
Total Kjeldahl Nitrogen (mg N/L)	25-39	1.5-3.1
Nitrate (mg N/L)	0.76-1	0.42-25
Orthophosphate (mg P/L)	2.86-4.2	1.66-4.6
Total Phosphate (mg P/L)	5.81-6.2	1.84-3.21

N = 4 samples, each parameter was analyzed in duplicate

Table 4. Influent and Effluent Data of Stabilization Ponds from Central Thailand.

Location	Province	Sample	pH	BOD_5 (mg/L)	TSS (mg/L)	TKN (mg N/L)	TP (mg P/L)
Panpoang	Ratchaburi	Influent	9.3	37	60	7.9	1.1
		Effluent	8.8	9	13	2.59	0.6
Potaram	Ratchaburi	Influent	7.3	72.4	193	53	5.1
		Effluent	7.3	3.5	7	19.5	3.1
Kanchanaburi	Kanchanaburi	Influent	7.4	10.4	9	13.2	1.4
		Effluent	7.5	24.3	4	5.3	0.8
Chaoum	Phetchaburi	Influent	7.3	12	45	11.3	1.05
		Effluent	8.9	14.1	28	6.2	0.6
Hua Hin (1)	Prachuap Khiri Khan	Influent	7.0	36	90	17.4	1.6
		Effluent	7.1	4.3	5	6	1.4
Hua Hin (2)	Prachuap Khiri Khan	Influent	7.0	3	7	4.4	0.4
		Effluent	7.8	3	7	7.5	0.8
Hua Hin (3)	Prachuap Khiri Khan	Influent	7.5	19.4	18	15	3
		Effluent	9.5	17.4	6	4.7	0.9
Prachuap Khiri Khan	Prachuap Khiri Khan	Influent	7.5	19.3	103	14.5	2.4
		Effluent	9.1	11.4	18	4.7	0.6

N = 1 sample, each parameter was analyzed in duplicate