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A CRITICAL ANALYSIS OF ECONOMIC FACTORS FOR DIVERSE WASTEWATER TREATMENT PROCESSES: CASE STUDIES IN THAILAND

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ABSTRACT

This paper analyzes the economic indicators for economically optimum yet appropriate wastewater treatment processes for Thai application. As a part of the technology selection process, the economic indicators including land requirements, construction costs, and operation and maintenance (O&M) costs of 53 municipal wastewater treatment plants are evaluated using data obtained from a questionnaire survey and secondary research. Using regression analysis, the study develops economic indicator models for four processes—activated sludge, oxidation ditches, aerated lagoons, and waste stabilization ponds. The analysis shows that land requirements and construction costs are functions of design capacity and can be represented in the form of a power regression ($y = ax^b$). O&M cost is related to the actual flow rate and can be modeled using linear regression ($y = a + bx$). Using the proposed models, the economic indicators for the identified alternatives in different scenarios are calculated and compared. Results show that waste stabilization ponds require much larger area than the other processes for the same size range. Activated sludge is the most expensive for all size ranges. With increasing plant capacities, the construction cost differences between activated sludge and the other processes becomes larger. Oxidation ditches have more expensive annual O&M costs than the other processes, even greater than activated sludge. In a follow-up study, the economic criteria of these four processes will be complied with data for other aspects (technical, social, and environmental) and local conditions to form a decision making model for selecting the appropriate wastewater treatment alternatives for Thailand.

INTRODUCTION

The failure of the Third World's urban environmental management, especially the urban sanitation infrastructure, results from two major factors—the shortage of resources and the deficiency of the delivery systems. Since the limitation of local resources is the prime issue in most developing countries, costs of the treatment system and land availability are among the foremost factors for selecting the most appropriate wastewater treatment system.

As a part of appropriate wastewater treatment selection, this study examines the economic aspects of various wastewater treatment processes for Thai application. Utilizing data collected from the existing Thai wastewater treatment plants (WWTPs), the paper analyzes land requirements, construction costs, and operation and maintenance (O&M) costs for activated sludge processes, oxidation ditches, aerated lagoons, and waste stabilization pond processes. The results from this study can be used as a guide for the general cost comparisons of proposed treatment alternatives and will be useful for planning the future wastewater treatment plants.

BACKGROUND

Factors determining appropriate wastewater treatment technologies differ from place to place according to the unique local urban contexts. Contextual differences exist even among developing countries. Apart from the technical factors, this paper, as a fol-

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low-up study, utilizes the economic factors of wastewater treatment processes to define the suitability aspects of technologies [1].

1. Economic Aspects of Appropriate Wastewater Treatment Systems

Land requirement: The availability of the land is one of major constraints determining the choice of wastewater treatment systems. In most cases, space sufficiency means not only the space to accommodate the size of the present facilities, but also the possibility of future expansion. Since most wastewater treatment systems are located outdoors, it may cause negative environmental impacts, such as noise and odor, on the surrounding residences. Therefore, system site and plot size should be sufficient to provide a buffer to minimize the visual, odor and noise impacts.

Affordability: The financial aspect considers not only the initial cost for construction and installation, but also the ability of the local community to pay for the continuing O&M costs. Treatment cost must reflect the level of household income and expenses [2]. In the context of developing countries, the ability-to-pay is an important issue, reflecting a reasonable and affordable payment for the user, which is determined by the type of wastewater treatment.

2. Economic Factor Data Analysis

Costs of land, construction, and O&M are the three major parameters of the total costs that are included in the economic analysis. Using the regression method, land usage and cost functions of wastewater treatment plants are usually expressed in the form of exponential Eq. 1:

$$y = ax^b \tag{1}$$

where *a* and *b* are calculated coefficients; and *x* is design capacity (flow).

This form has been widely used to express and compare land area requirements, construction costs, and O&M costs among wastewater treatment alternatives [3-9]. The results of this analysis can be used as a guide for the general cost comparison of alternatives in a decision making process. In this paper, the results and equations of land requirements and construction cost values are produced for specific systems and presented with respect to the design flow ($m^3\ d^{-1}$). O&M costs are presented in relation to the actual flow rate of each plant (details will be discussed later in this paper).

3. The State of Wastewater Treatment in Thailand

In Thailand, most WWTPs exist only in municipal or urban areas, due to the lack of budget and other resources. There are 95 wastewater treatment projects

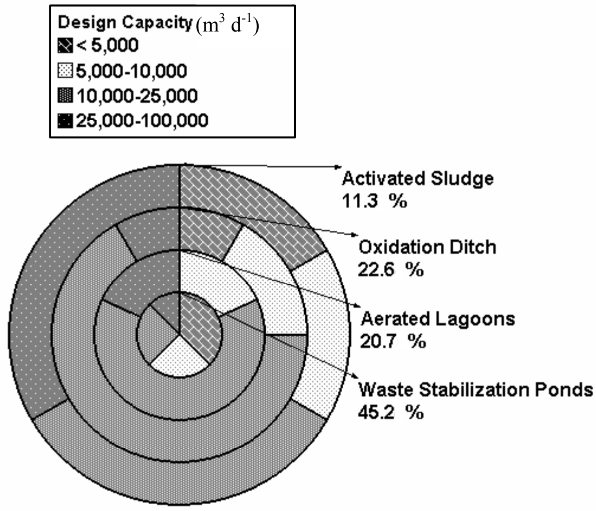

Fig. 1. Type and size distributions of municipal wastewater treatment systems in Thailand.

(including seven plants in Bangkok Metropolitan area) with the total capacity of 3 $Mm^3\ d^{-1}$, equivalent to approximately 20% of wastewater generated.

In most circumstances, treated wastewater in Thailand is discharged to nearby inland waters such as canals and rivers where maintaining an adequate dissolved oxygen concentration is necessary. In this light, secondary treatment is required because primary treatment alone is insufficient to treat the wastewater to the target quality. Among the various wastewater treatment processes, four types of secondary wastewater treatment alternatives that are widely used to treat domestic wastewater in Thailand are considered in this study: Activated Sludge (AS); Oxidation Ditches (OD); Aerated Lagoons (AL); and Waste Stabilization Ponds (WSP). All alternatives are aerobic biological processes. The first two processes are forms of aerobic suspended-growth biological treatment. The other two processes are types of lagoon or pond treatment systems.

Figure 1 shows the type and size distribution data for 53 municipal WWTPs used in the study. The WSP process is the most frequently used treatment process in provincial areas (45%) due to its simplicity and the availability of land. The AS process, on the other hand, is rarely used (11%) due to high energy requirement and O&M complexity. Most treatment plants are in the medium size categories with the design capacities of 10,000-25,000 $m^3\ d^{-1}$.

METHODS

The study utilized a plant survey to acquire information regarding the characteristics of Thai municipal WTTPs. A mail questionnaire survey was conducted with plant operators of 63 treatment facilities during the months of February and June 2007. A total of 32 respondents participated in the survey (51% response rate). An additional 21 plants were added using information from government maintained databases [10]. A total 53 WWTPs were used to analyze economic criteria.

RESULTS AND DISCUSSION

1. Land Requirements

The size and availability of land are the primary criteria determining the choice of wastewater treatment process. The area needed for a municipal system usually depends on the level of treatment, types of treatment systems and processes, and the size of a treatment plant [8].

Figure 2 presents average values of land requirements per design flow (m^3 d^{-1}) for different processes from 28 different treatment plants. These data represent the entire area of the facilities including plant footprints, pathways, offices, etc. The overall data show, as expected, that more advanced processes such as AS and OD require less area than the natural treatment systems. WSP requires the most space per m^3 of daily design flow, or about 10 times more area than the space required by AS and OD. Figure 2 also shows the average area required per m^3 of daily design flow for plants ranging in size from less than 5,000 to 100,000 m^3. There is a presumption that larger plants generally require less land per unit served due to an economy of scale. Graphs in Fig. 2 clearly show a strong economy-of-scale trend in WSP process, for which the amount of land required per m^3 of design flow decreases as the size of treatment plant increases.

Within the context of wastewater treatment projects developed in Thailand, data show that the selection of treatment processes for municipalities were attributed to their levels of urbanization and availabilities of lands. In highly urbanized municipalities and tourism areas, such as Pataya, Hua Hin and Phuket, where most of the economic activities are concentrated around these cities, land availability for a wastewater treatment project is very limited and expensive. The choices of treatment process and plant size tend to be a function of land cost. Data show that an energy-intensive process particularly the AS process is one of the most preferable treatment alternatives in those areas. In lesser developed municipalities where large plots of land are inexpensive and available, pond or lagoon systems are commonly used. Beside the urbanization factor, the choices of treatment process and plant size also depend on the availability of government land. In order to avoid buying private owned land, the government usually provides land to local authorities for wastewater treatment projects at no financial cost.

In Fig. 3, the values of land requirements in m^2 for the four processes are graphically presented as a function of design capacity (m^3 d^{-1}). Models for land

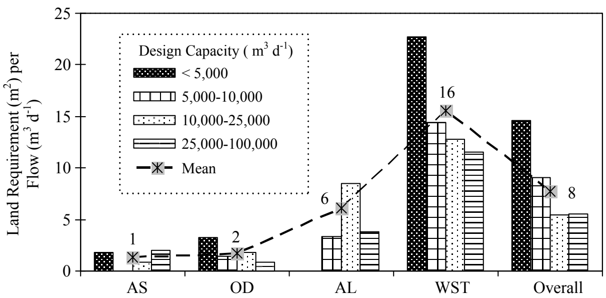

Fig. 2. Land requirements for different processes and design capacities.

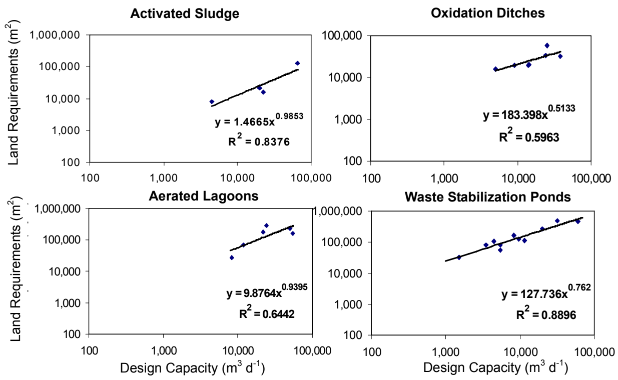

Fig. 3. Land requirements for identified wastewater treatment alternatives.

requirements give a good fit to the data of all processes except for OD. With very high R^2 values, area requirements for AS and WSP can be well explained by their design capacities. Nevertheless, the moderately high R^2 of 0.64 for AL and 0.60 for OD models could indicate an acceptable goodness of fit between the design capacity and land area requirement variables, suggesting a fairly strong predictive potential for the models. Based on graphical data in Fig. 3, the equations produced to express the land requirements are summarized in the form of $L = aQ^b$ in Fig. 3 (Table 1).

2. Construction Costs

The costs of construction mainly depend on the capacity of the installation, which is expressed either by design flow or by served population size; the quality of raw sewage to be treated; and the level of wastewater treatment required [8,9]. This study uses cost information from the survey and documented data [10] to develop predictive equations. Construction costs and corresponding design flows of 53 municipal WWTPs throughout Thailand are evaluated.

Figure 4 shows the effect of design capacities on construction costs in different processes and sizes. Data of AL and WSP show that construction costs per m^3 d^{-1} decrease with increasing plant size, due to an economy of scale. Because of a small number of AS

Table 1. Land requirements and construction costs for wastewater treatment alternatives in relation to design capacities ($m^3\ d^{-1}$) and its annual O&M costs in relation to actual flows ($m^3\ d^{-1}$)

System	N	Models	R^2
Activated sludge	4	$L = 1.467\ Q^{0.985}$	0.838
Oxidation ditches	7	$L = 183.398\ Q^{0.513}$	0.596*
Aerated lagoons	6	$L = 9.876\ Q^{0.940}$	0.644*
Waste stabilization ponds	11	$L = 127.736\ Q^{0.762}$	0.890**
Activated sludge	6	$C_c = 0.0031\ Q^{0.881}$	0.979**
Oxidation ditches	8	$C_c = 0.0017\ Q^{0.910}$	0.604*
Aerated lagoons	11	$Cc = 0.0143\ Q^{0.681}$	0.822**
Waste stabilization ponds	23	$Cc = 0.0004\ Q^{1.060}$	0.790**
Activated sludge	4	$C_{O\&M} = 0.0529 + 1.31\times10^{-5}\ F$	0.996**
Oxidation ditches	10	$C_{O\&M} = 0.0963 + 1.02\times10^{-5}\ F$	0.789**
Aerated lagoons	8	$C_{O\&M} = 0.0607 + 3.31\times10^{-6}\ F$	0.693**
Waste stabilization ponds	19	$C_{O\&M} = 0.018 + 4.03\times10^{-6}\ F$	0.694**

*p < 0.05; **p < 0.01

L = Land requirement (m^2); Q = Design capacity in $m^3\ d^{-1}$; C_C = Construction cost (million USD); $C_{O\&M}$ = Annual operation and maintenance cost (million USD); F = Actual flow in $m^3\ d^{-1}$.

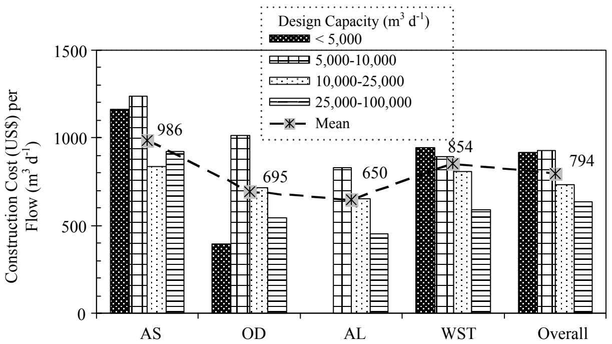

Fig. 4. Construction costs for different processes and design capacities.

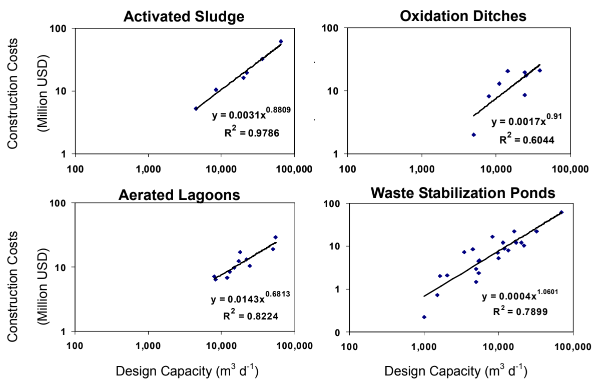

Fig. 5. Construction costs for identified wastewater treatment alternatives.

and OD plants, the result in small size categories shows very little economy of scale for these processes. AS shows the highest construction cost per volume compared to other processes except in the 10,000-25,000 $m^3\ d^{-1}$ category. For this group, AS and WSP data show comparable high construction costs per m^3 treated.

Since the treatment plants were built and operated during different time periods, the construction cost (in Thai Baht) of each plant is adjusted to give the present value (PV) in the year 2007. The PV of the historical cost (HC) is calculated by using Eq. 2:

$$PV_t = HC_t \times (1+f_t)^{t-1} \quad (2)$$

where f_t is inflation at different time t.

The present value of construction costs are converted to US dollar according to the official exchange rate in 2007 (1 USD = 34.5 Baht) [11]. The construction cost functions of wastewater treatment processes are expressed in the form of $C_C = aQ^b$, where C_C is construction cost; Q is design flow ($m^3\ d^{-1}$); and a and b are calculated coefficients.

Within the flow range of 1,000-78,000 $m^3\ d^{-1}$, Fig. 5 and Table 1 provide best fit equations for estimating construction costs for AS, OD, AL, and WSP processes. These power regression equations are statistically significant ($p \leq 0.02$) with acceptably high R^2, indicating that the proportional construction cost is greatly determined by the plant size.

3. O&M Costs

The annual O&M costs include the total cost of four major components: personnel, energy, equipment & chemical, and maintenance costs. The major factors influencing the O&M costs include the treatment processes and target effluent qualities to meet standard requirements. The study considers the past year's O&M costs for WWTPs that are in operable condition with similar effluent quality requirements. Plants in very poor condition and subjected to major overhaul or shut down during the survey are not considered in the analysis. The O&M costs are related to the actual flow rather than design capacity.

Figure 6 shows the overall annual O&M costs

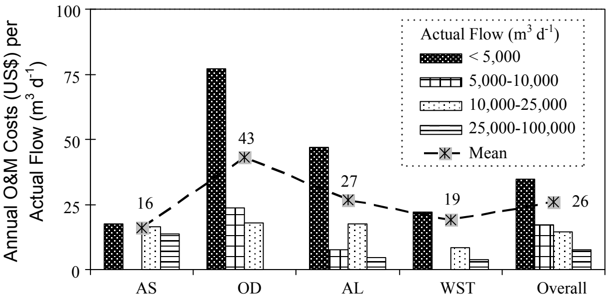

Fig. 6. Overall annual O&M costs for different processes and actual flows.

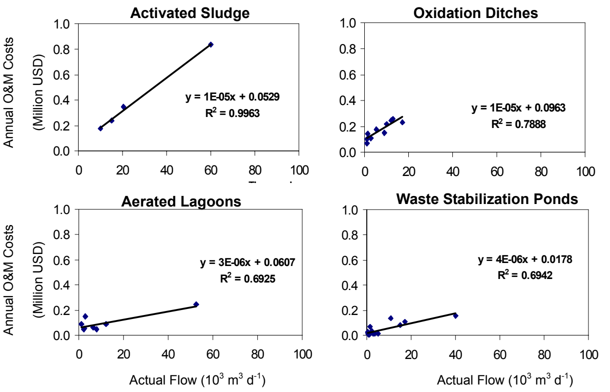

Fig. 7. Annual O&M costs for identified wastewater treatment alternatives.

per actual unit of flow (m^3 d^{-1}) for different treatment processes and sizes. The general trend of economy of scale is observed as the actual flows to the plants increase. Natural processes like WSP require 55-70% lower O&M costs per volume of wastewater than the more advanced and energy intensive processes, i.e. AS and OD. In the small flow category (< 5,000 m^3 d^{-1}), data show the highest O&M costs in OD process followed by AL and WSP systems. The O&M costs of medium-sized AS and OD processes are somewhat comparable.

The results of regression analysis are shown in Fig. 7 and Table 1. Data show that the linear regression models give the best fit for estimating O&M costs for all considered treatment processes. The linear regression equations are statistically significant ($p < 0.01$) with high R^2. The annual O&M costs are considerably affected by the volume of wastewater being treated.

4. Estimate of Economic Indicators

Using 200 L cap^{-1} d^{-1} of average wastewater production for developing countries, approximately 70% or 140 L cap^{-1} d^{-1} of water consumption will be discharged to collecting sewers (if available) or to receiving water [12,13]. Considering flow variations, the study estimates the total design flow generated from residential unit by using the rate of 210 L cap^{-1} d^{-1} or

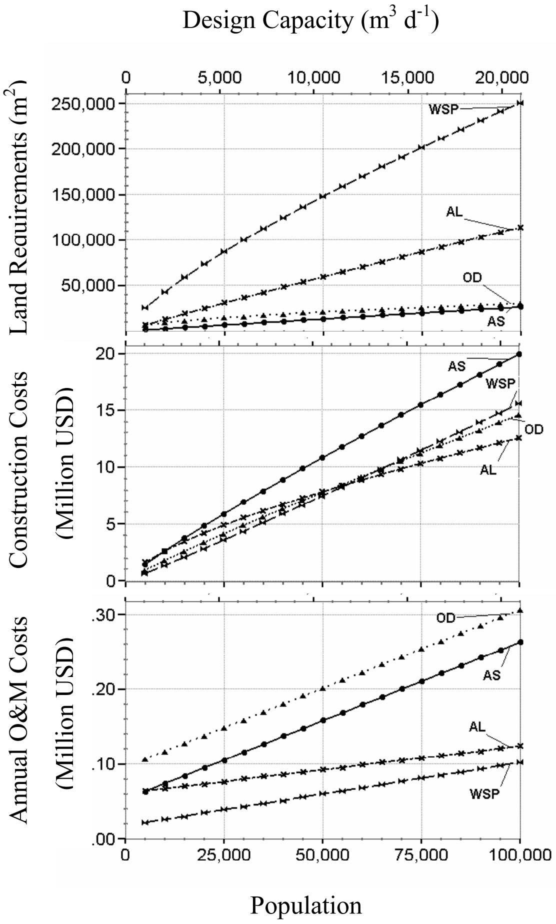

Fig. 8. Economic indicators for wastewater treatment alternatives.

about 1.5 times the average sewage flow (140 L cap^{-1} d^{-1}). The economic indicators for the four wastewater treatment alternatives are compared in Fig. 8.

Figure 8 shows that WSP requires much larger space for installation than the other processes with the same design capacity range. The area required for AL appears to be in the middle between the natural pond system and the energy-intensive systems. The land requirement for OD is slightly more than the land required for AS.

In terms of construction costs, AS is the most expensive installation for all ranges of plant sizes. With the increasing plant capacities, the construction cost for AS grows accordingly and the cost differences between AS and the other processes become larger. It is also interesting to observe that WSP process becomes more expensive than AL and OD when the plant sizes are approximately larger than 12,600 m^3 d^{-1} or serving more than 60,000 people.

The annual O&M costs for AS and OD are the highest for all ranges of design capacities. From the calculated results, the OD system, which is operated as an extended aeration AS process, consumes the highest O&M among all considered processes. On the other hand, the graphs clearly show that WSP is the most economical process for Thailand.

CONCLUSIONS

A set of proposed economic indicators from a previous study are used to assess the operating municipal WTTPs in Thailand. The paper demonstrates the economic criteria analysis of four wastewater treatment processes. The predictive equations of land requirements, construction costs, and O&M costs for those different processes are proposed with the limitations for Thailand application and other developing countries having similar context. To develop a decision making model for selecting an appropriate wastewater treatment system, the equations can be used to calculate the economic indicators for the identified wastewater treatment alternatives in different case studies (in the follow-up study).

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REFERENCES

1. Singhirunnusorn, W. and M.K. Stenstrom, Appropriate wastewater treatment systems for developing countries: Criteria and indicator assessment in Thailand. Water Sci. Technol., 59(9), 1873-1884 (2009).
2. Sarmento, V., Low-Cost Sanitation Improvements in Poor Communities: Conditions for Physical Sustainability. Ph.D. Dissertation, University of Leeds, Leeds, England (2001).
3. Muiga, M.I. and G.W. Reid, Cost analysis of water and wastewater treatment processes on developing countries. Water Resour. Bull., 15(3), 838-852 (1979).
4. Aivaliotis, V., T. Giannakopoulou, M. Gratsiou and D. Panagiotakopoulos, Economies of scale and strategic planning for municipal waste treatment plants in Greece. Constr. Manage. Econ., 9(6), 553-564 (1991).
5. Okubo, T., K. Kubo, M. Hosomi, and A. Murakami, A knowledge-based decision support system for selecting small-scale wastewater treatment processes. Water Sci. Technol., 30(2), 175-184 (1994).
6. Balmér, P. and B. Mattsson, Wastewater treatment plant operation costs. Water Sci. Technol, 30(4), 7-15 (1994).
7. Li, X.W., Technical economic analysis of stabilization ponds. Water Sci. Technol., 31(12), 103-110 (1995).
8. Tsagarakis, K.P., D.D. Mara and A.N. Angelakis, Application of cost criteria for selection of municipal wastewater treatment systems. Water Air Soil Poll., 142(1-4), 187-210 (2003).
9. Friedler, E. and E. Pisanty, Effects of design flow and treatment level on construction and operation costs of municipal wastewater treatment plants and their implications on policy making. Water Res., 40(20), 3751-3758 (2006).
10. Pollution Control Department, Survey Report: The Evaluation of System Efficiency of Municipal Wastewater Treatment Plants in Thailand. Water Quality Management Bureau, Pollution Control Department, Ministry of Natural Resources and Environment, Bangkok, Thailand (2003). (in *Thai*).
11. Bank of Thailand, Rates of Exchange of Commercial Banks in Bangkok Metropolis (2002-present). http://www2.bot.or.th/statistics/ReportPage.aspx?reportID=123&language=eng (Feb. 2009).
12. Ludwig, H.F., H. Fennerty, K.L. Sow and K. Mohit, Textbook of Appropriate Sewerage Technology for Developing Countries. South Asian Publishers PVT, New Delhi, India (2005).
13. Pollution Control Department (PCD), Domestic Wastewater and Wastewater Treatment Systems. http://www.pcd.go.th/info_serv/water_wt.html (Sept. 2008). (in *Thai*)

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