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HDPE Pipeline Length for Conditioning Anaerobic Process to Decrease BOD in Municipal Wastewater

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Abstract

The Phetchaburi municipal's sewer system for transporting wastewater to treatment system at The Royal LERD project comprise with a gravity sewer, a Klongyang collection pond and the 18 km-HDPE pressure pipeline that allows for a retention period of the wastewater. Consequently, this research focuses on the treatment of the wastewater during the transportation phase of the sewer system. The results are generally concluded that the municipal wastewater compromises with easily biodegradable organic matter, mesophile temperature and abundant nutrients that promote self-biodegradation in both anaerobic and aerobic processes. The BOD concentration at the municipal's point sources was found to be around 907 mg/l, as the retention time on the gravitational system allows for both aerobic and anaerobic digestion process to decreases its concentration. During the transportation phase in the HDPE pipeline to The Royal LERD Project found that only anaerobic process occurs. After reaching 12 km in the HDPE the digestion rate trend to be zero with the 35.2 hours retention time. The BOD concentration reaching The Royal LERD project was found to be 52 mg/l with 94% efficiency. The knowledge gained from this experiment proved that the self-purification processes happened in the sewer system, which help supports domestic wastewater treatment.

Keywords: domestic wastewater; sewer system; self-purification; wastewater treatment

1. Introduction

Wastewater from households, officials, fresh food markets, schools and buildings in a city can be call domestic wastewater or municipal wastewater. As activities such as cooking, washing, bathing and excreting, generate wastewaters containing complex elements. In order to understanding about the composition of domestic wastewater, we must take into consideration about the organic compound that played a role as the main pollutant in the domestic wastewater, this includes biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Sawyer, 2003; Metcalf and Eddy, 2004; Henze, 2008). Moreover, domestic wastewater is polluted with nutrient, nitrogen and phosphorus, that enough for biological digestion process by microorganism (Arceivala, 1973).

In many wastewater treatment plants, especially high technological process, it is often found that some pollutants in domestic wastewater cannot be treated to under standard according to the BOD loading. This is due to a lower design and reasonably the degradation process has been done at a primary treatment system (e.g. septic tank) and during transporting in sewer system (Nielsen et al., 1992; Ashley et al., 1999; Hvitved-Jacobsen et al., 1999; Konnerup et al., 2009). For example, Centralized wastewater treatment plants (CWTs) in Bangkok have low removal efficiency of nitrogen due to their insufficiency of organic carbon for nutrient degradation process. There are many factors affect the carbon source lower than the design value. (Noophan et al., 2007; Noophan et al., 2009; BMA, 2012). Where currently there is very few supporting studies on the wastewater pipelines as a base knowledge to the sewage system management and design the wastewater treatment plants in Thailand.

Phetchaburi municipal wastewater is collected and transferred through the sewer system to treat at The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project (LERD) (Figure 1) that initiated by King Rama the 9. It was constructed at Laem Phak Bia sub-district, Ban Laem district, Phetchaburi province, Thailand, (1442240 to1443480 N and 0617780 to 0619271E), which is far away from Phechaburi urban zone. There are 4 technologies of wastewater treatment under the nature process, oxidation pond, plant filtration, constructed wetland and mangrove forest for treating the wastewater to standardized conditions before being released to mangrove forest and Gulf of Thailand (Chunkao et al., 2014). Evidently, the wastewater is held in the sewer system for a period of time causing its characteristics to changed. Consequently, this research focused on the treatment

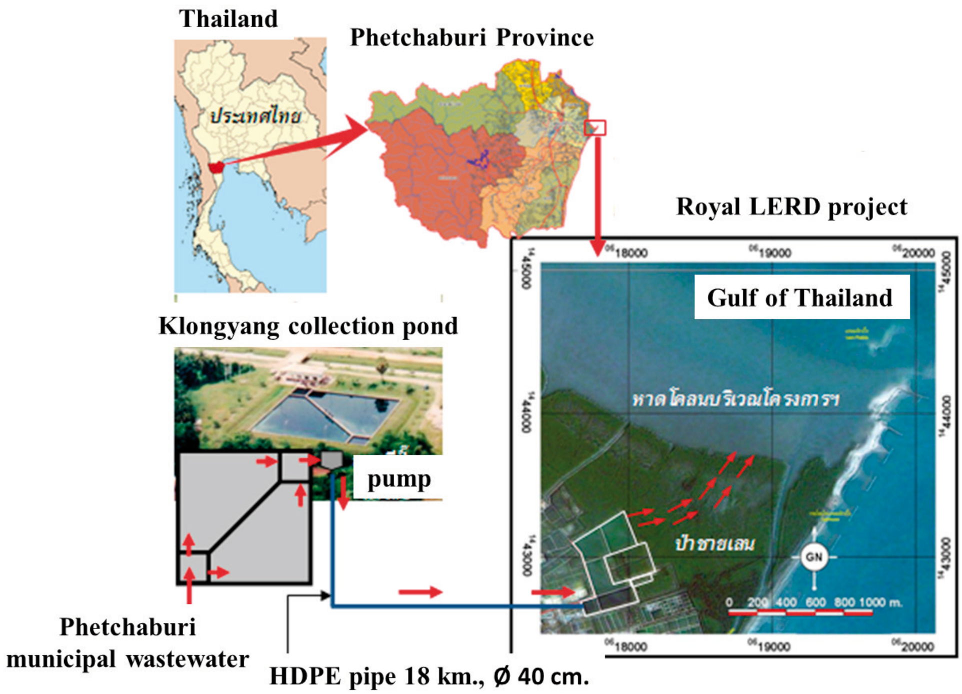


Figure1. Location of Phetchaburi and Royal LERD project site

of Phetchaburi municipal wastewater during transporting in sewer system since leaving from households until release to LERD project. The results would be to applied and managed domestic wastewater in other cities.

2. Materials and Methods

2.1. Phetchaburi sewer system

Phetchaburi municipality located in Phetchaburi province, center of Thailand, it covers an area of 5.4 km^2 and has population 27,556 in 2015.The wastewater from households, fresh-food markets, schools, shopping malls and offices is drained to sewer system and transferred to Klongyang collection ponds (Equalization pond). The sewer system was constructed underground with both rectangular and circle cross section ranging from 0.3-1.5 meters diameters. The flow of the wastewater is designed according to gravity. However, when crossing the Phetchaburi river the assistance from an electronic pump is used to assist the flow. The Urupong bridge station, Thasrong bridge station, Yai bridge station, Dam bridge station and Chom klao bridge station are the 5 cross over sections that requires the subordinate pumping stations (Figure 2).

The general scheme of the collection pond compromise of 2 small and 2 big ponds with the total volume

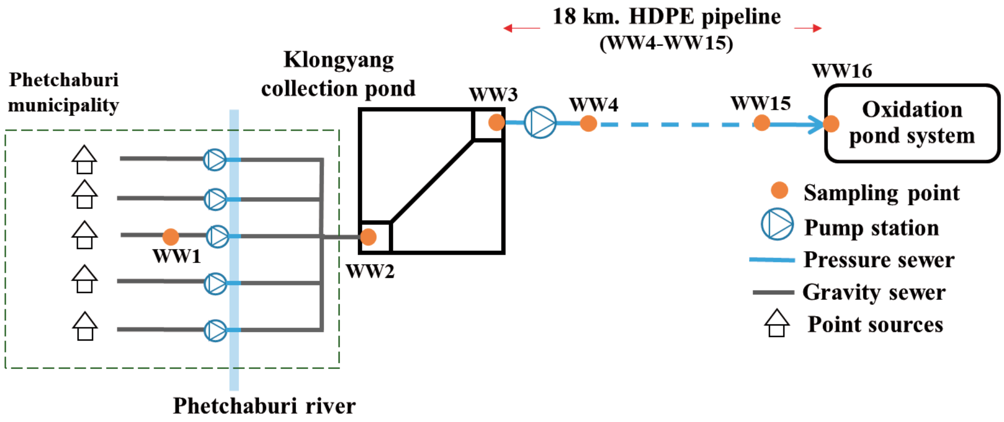


Figure 2. Schematic diagram of the Phetchaburi municipal sewer system and sampling points

7,200 m^3 (Figure 2). The small pond first receives the wastewater from the city while the other pond acts to supports the wastewater before pumping into LERD project. The main function of two big ponds is for wastewater storage, preparing them for the treatment plants continuously. The Klongyang collection pond consist of alternating 3 pumps, with 1 working and 2 on standby, the purposes of these pumps are for increasing head water and making the wastewater flowed through a 400 millimeters diameter, 18-km length HDPE pipeline to the sedimentation pond, the first pond of oxidation pond system in the LERD project.

2.2. Wastewater sampling

Water sampling is a crucial method that is required to monitor the changing of quality of the wastewater. Sampling points located along the 18-km HDPE pipeline at 12 blow offs locations. However, to complete the whole system in testing for the water quality, it is important that another 4 more collections sites were added to this sampling method. With now the combine total of 16 samples being collected by grab sampling.

The first 15 samples were then collected at different location along the sewer system. The first one (WW1) where the sample is being collected at a random manhole of the combine sewer system. The second (WW2) and the third (WW3) sampling points were in Klongyang collection pond at the small first pond and the small last pond respectively. The next 12 sampling points (WW4-WW15) located on 12 blow offs along the 18 kilometers HDPE pipeline. The sampling time of wastewater at each blow offs had to relate with the transferring time of mass of wastewater throughout pressure pipeline. Finally, the last one point (WW16) be at the end of the HDPE pipeline, the inlet sedimentation pond (Figure 2). As the Wastewater sampling were conducted 2 times on October, 2014 and April, 2015 representing the wet and dry period respectively. The wastewater flow rates in HDPE pipeline were measured by ultrasonic flow meter, which calculated the velocities and timings.

2.3. Wastewater quality analysis

To ensures that the water quality reflects it's true value some physical and chemical parameters were immediately measured after the wastewater were taken out of the flow system, parameters including temperature, dissolve oxygen (DO) and pH. Thus, other parameters that required a more high-end laboratory equipment is then kept at 4°C in PE 1-liter bottle during its transferring to the laboratory. The analysis of wastewater followed with the Standards Methods for the Examination of water and wastewater (1998).

There are 6 parameters that defined by The Pollution Control Department (PCD), Ministry of Natural Resources and Environment, is needed to be consider; biochemical oxygen demand (BOD), pH, suspended solid (SS), total nitrogen (total-N), total phosphorus (total-P) and oil and grease (PCD, 2012). Not only these indicators, but also COD and DO are used as the main indicators that were taken into consideration for the changing composition of wastewater during transporting in the sewer system by a graphical method which includes a free hand curving.

3. Results and discussion

3.1. Retention time of the wastewater in Phetchaburi sewer system

A sewer system of Phetchaburi municipal can divide 3 parts. The combine sewage system that collect and deliver wastewater from point sources to Klongyang collection pond, the Klongyang collection pond and 18-km HDPE pipeline system. The retention time for transporting of the wastewater from point sources to the collection pond depends on the amount of the wastewater and the distance between them. The distance from the point sources to the collection pond ranges from 4.5 km to 0.5 km respectively. The flow rate of the wastewater normally designed to be 0.6 m/s as this prevents the settle solid, together the retention time ranges from 2-0.1 hr. (average retention time 1.2 hr)

For an effective treatment, a 1-day of retention time is required for the collection pond to sufficiently supply the wastewater continuously to treatment plants (Metcalf and Eddy, 2004). The capacity of Klongyang collection pond is 7,200 m3 by volume. The daily average discharge delivered to LERD project is equivalent to 5,910 m^3/day, so, this calculates for the retention time to equal 29 hours. From the collection pond to the oxidation pond system, at Royal LERD project, the wastewater is flowed at average discharge 303 m^3/hr, velocity 0.7 m/s and 7.5 hours of retention time through 18 km long HDPE pipeline. The

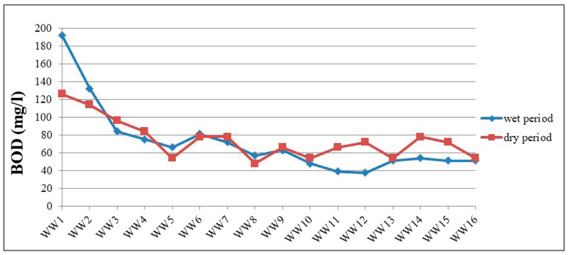
Table 1. Flow rate and travelling time of domestic wastewater in 18 km HDPE pipeline

Sampling point	Detail	Distance from collection pond (km)	Wastewater travelling time (hr)
WW1	sewer in city zone	-	-
WW2	first collection pond	-	-
WW3	last collection pond	0.0	0.00
WW4	blow off 1	0.1	0.04
WW5	blow off 2	1.3	0.54
WW6	blow off 3	3.0	1.24
WW7	blow off 4	4.5	1.87
WW8	blow off 5	6.0	2.50
WW9	blow off 6	7.5	3.09
WW10	blow off 7	9.0	3.75
WW11	blow off 8	9.6	3.97
WW12	blow off 9	12.5	5.18
WW13	blow off 10	14.1	5.83
WW14	blow off 11	15.7	6.53
WW15	blow off 12	17.2	7.15
WW16	Sedimentation pond	18.0	7.46

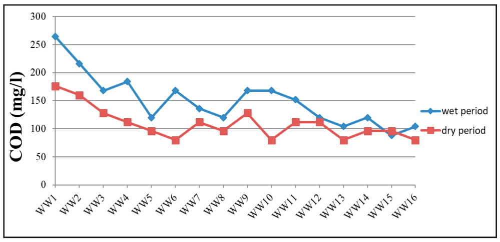
distance and travelling time of the wastewater during under pressure HDPE pipeline of each sampling point from Klongyang collection pond were represented in table 1. Mentioned above, Phetchaburi municipal wastewater have its retention time from the point sources to the collection pond averaging in about 1.2 hours, 29 hours inside the collection pond, and 7.5 hours from the collection pond to the treatment plant. This brings the total retention time to 37.7 hours. This retention period allows for change in physical, chemical and biological characteristics of the domestic wastewater. (Nielsen et al., 1992; Hvitved-Jacobsen et al., 1999; Qteishat et al., 2011; Poommai et al., 2013)

3.2. Wastewater quality analysis

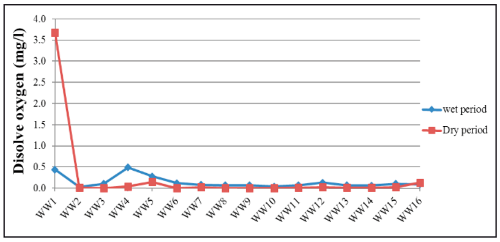
The result of physical, chemical and biological of wastewater indicators shows that all indicators were changed during transporting in the sewer system. At first point (WW1), BOD:COD ratio was 0.7 in both rainy and dry season and the average ratio values at all the sampling points were 0.5 and 0.7 in rainy and summer season respectively. This means that Phetchaburi municipal wastewater can be easily biodegraded as to the likes other cities in Thailand including Bangkok, Khon Kaen, and Chiang Mai, where the value of BOD/COD more than 0.5 (Noophan et al., 2009; Konnerup et al., 2009; Tsuzuki et al., 2010).



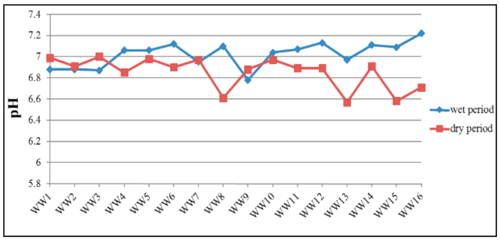
Δ (1) BOD



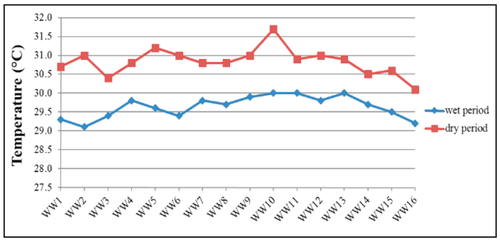
Δ (2) COD



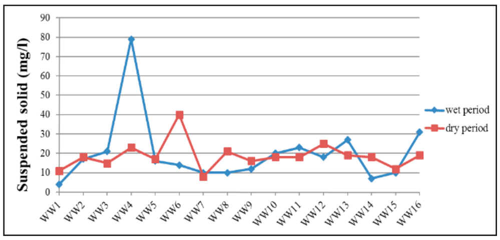
Δ (3) Dissolve oxygen



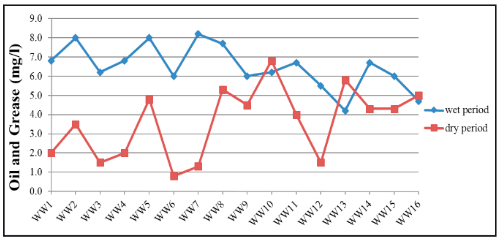
Δ (4) pH



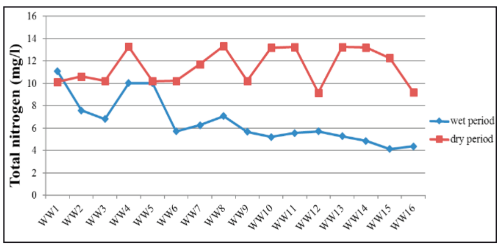
Δ (5) Temperature



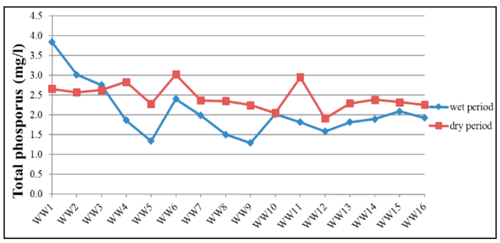
Δ (6) Suspended solid



Δ (7) Oil and grease



Δ (8) Total nitrogen



Δ (9) Total Phosphorus

Figure 3. Wastewater indicators for each sampling point of the sewer system (WW1-WW16)

Illustrated in figure 3 are the values of 9 initial wastewater indicators, BOD, COD, DO, pH, temperature, suspended solid, oil and grease, total nitrogen and total phosphorus for each sampling point of the sewer system (WW1-WW16).

From the quality analysis, conducted by the aerobic and anaerobic process, which consisted of suspended, biofilm and sediment microorganism. The organic matter that can be defined by BOD and COD, which decomposed rapidly at the third sampling point, the combine sewer system in the urban zone (WW1) and Klongyang collection pond (WW2-WW3). Dissolvable and suspended organic compound consisted of digestible and non-digestible organic substrates are the main components in domestic wastewater as these includes are carbohydrates, proteins, fats, lignin, synthetic detergents and cellulose etc. Qteishat et al. (2011) and Orhon et al. (1997) discovered that 80% of domestic wastewater contain organic compounds which are biodegradable, where in fresh domestic wastewater these dissolved organic compounds will aerobically and anaerobically be used microorganism to directly forms new cells and energy. While in slow biodegradable substrates, particulate material (colloidal) and complex organic molecules. The process of hydrolysis takes place first where these substrates are transformed in dissolvable compound as microorganism are able to benefits from them. The key factor that supports the decomposition process consisted of many supporting values where the wastewater compromises of biological stage which are easily biodegradable, while also providing the optimal temperature ranges from 29-31.5 degrees celsius that are favorable for biochemical reaction and optimal carbon source per nutrients that is represented by the average BOD:N:P of the first three sampling points being 100:6.5: 2.5 and 100:9.3:2.4 of the wet and dry season respectively.

The wet season provides a higher values in BOD at 2 first sampling points and COD at almost sampling points than the dry season, this suggested for three major reasons. First, the organic matter and oil from vehicles that often spills out onto roads are washed and polluted the runoff into the sewer system. Where in relational to the values of the oil and grease values it was found in rainy season the values of the first three sampling points were higher than the dry season. Secondly, the runoff allows for small particles to turbulently displaced in the form of suspended soils. Lastly, the BOD factor can be depended on activities at the point of sources. As this combine process could have resulted to lower DO concentration due to higher consumption of oxygen for biodegradation in wet season.

The highest DO values in dry period found at WW1 (3.68 mg/l) however, in the wet period, WW1 and WW4 were the highest. Having it's value 0.44 and 0.49 mg/l respectively. Not only fresh wastewater comprises of a high DO concentration, but also a low rate of oxygen consumption by microorganism at first sampling point. After the wastewater have flowed into the sewer system, the rate of degradation increases due to the microorganism in the wastewater has now becomes familiar with wastewater thus affecting the oxygen consumption higher than reaeration rate by nature process. Undoubtedly, the DO values approaches zero although at the Klongyang collection pond is an open air system. Seeing the DO spike in the WW4 (blow off 1) during rainy season, it is clear that there are outside factors that changed the values as suggested that this could be the cause of rainwater adding DO into the collection pond. After the DO spike we see that the DO drops back down to near zero instantaneously as oxygen are used for the aerobic processes, which turns the digestion process quickly into the anaerobic in the 18 km HDPE pipeline until the end.

From the free hand curve, the BOD concentration in wet period trended to constant out at 48 mg/l after the wastewater have flowed 12 kilometers in distance and remains constant throughout the 18-km HDPE pressure pipeline, or about 5.0 hours from Klongyang collection pond. This tendency lead to a constant and faster flows in summer period distance 8 kilometer, 3.3 hours, but it slightly more BOD value at 62 mg/l. The distance and time according with constant of BOD concentration also corresponds with the temperature that gradually increase to the highest value in the rang sampling point of WW10-WW11 or 9.0-9.5 km from the collection pond both wet and dry period and gradually decrease till the end of the sampling point. With the digestion process increasing the temperature this suggested that the anaerobic process decel erates leading to the decrease in wastewater temperature (Svoboda, I. F. 2003; Metcalf and Eddy, 2004). There are three reasons supporting BOD concentration trended to constant, firstly there are hard to digest, such as particulate organic matter, cellulose and oil and grease (Sawyer et al., 2003). Secondly, the limiting factor for anaerobic degradation process during wastewater transporting in 18-km HDPE is a low carbon source, while high nitrogen and phosphorus in both wet and dry periods have shown the average ratio of BOD:N:P (WW4-WW16) equaling to 100:10.9:3.3 and 100:18.4:3.7 respectively, while the appropriate ratio for anaerobic process equal 100:1.1:0.2 (Metcalf and Eddy, 2004). Lastly, the by-products from the anaerobic digestion process includes organic acid and sulfide which may inhibits the biodegradation process.

For the other parameters that is defined as a standard of domestic wastewater indicators, (oil and grease, suspended solid and nutrients, total nitrogen and phosphorus). The Oil and grease concentration varied during transporting in the sewer system because it was made in form of emulsified oil. As household wastewater is polluted with emulsifiers such as detergent, soap, furthermore, the Phetchaburi municipal wastewater also flowed through a turbine at the pumping station in the Klongyang collection pond, as these may also induce emulsion of oil into domestic wastewater (Aurelle, n.d.; Pearce, 1978; Marchese, 2000; Gryta et al., 2001). The suspended solid (SS) values have also shown an increase at the first four sampling points in both wet and dry period, as this is mainly due to the increasing of microorganism cell. In aerobic condition, especially, promotes the growth of heterotrophic biomass associated with decomposition of organic substrate and oxygen uptake (Jensen, 1995). The SS values at WW4 in the wet period and WW6 in dry period were jumped because the sediment at the bottom of pond feeding wastewater into pumping station was diffused due to a turbulent flow. The nutrients, nitrogen and phosphorus, are essential for microbial cell synthesis and growth of biodegradation in both anaerobic and aerobic process. Undoubtedly, this would result in the total nitrogen and phosphorus decreased during transporting in the sewer system (Chernicharo, 2006). The higher water temperature often resulted in more anaerobic reaction rate as volatile fatty acids are produced thus making the pH values in summer period lower than wet period (Arceivala, 1973).

From the analysis of LERD (2015), it is suggested that the 907 mg/l of the BOD average of wastewater point sources consisted of commercial, fresh food markets and living areas of Phetchaburi municipal. Using the above information as the base study guide also suggested that the Phetchaburi municipal sewer system in transferring the wastewater to the treatment plant from the mentioned point sources have presented us with a 94.5% efficiency.

The compositions of domestic wastewater from Phetchaburi municipal and other cities in Thailand can easily treated by biological process, especially readily on the biodegradable organic matter. Moreover, it comprises with abundant of nutrients, nitrogen and phosphorus. The main functions of sewer system are not only collecting and delivering of domestic wastewater from point sources to wastewater treatment plants (WWTPs), but also can be used for treating pollutants in wastewater. Besides the design of the sewer system has a direct effect on the compositions of wastewater as this is depended on hydraulic flow and shear force, reaeration, sedimentation and resuspension of wastewater (Nielsen et al., 1992; Qteishat et al., 2011).

3.3. Wastewater treatment by nature by nature process

From the water quality assessment of 2011 to 2015 Of the LERD project the average BOD, Total-N and Total-P was projected to be 12.48 mg/l, 0.23 m/l and 4.36 mg/l respectively.

While in comparing the water assessment of 8 mega wastewater treatment plant of Bangkok from 2011-2015 which consisted of the Rattanakosin, Si Phraya, Chong Nonsi, Thung Khru, Nong Khaem, Din Daeng, Chatuchak and Bang sue. Where their average BOD, total-N and total-P ranges from 10.99-4.31 mg/l, 0.47-1.14 mg/l and 5.15-10.06 mg/l respectively, as this demonstrates that the AS technology is able to reduce the BOD to lower than the oxidation ponds system. However, in the total-N and total-P load the oxidation ponds shows a higher efficiency rate as this is base on the nutrients in the wastewater are being taken up by the microorganism as they are being uptake by the phytoplankton in the natural processes.

This study is represented by the BOD:N:P ratio at the end of Phetchaburi municipal sewer system (WW16) equivalent to 100:8.6:3.8 and 100:17.2:4.2 in wet and dry season respectively. This means that the proportion of organic carbon and nutrient is not suitable for mechanical aerobic treatment such as activated sludge, oxidation ditch, that require BOD:N:P ratio as 100:5:1. From the report of BMA (2012) and Noophan et al., (2009) presented that although almost all of the centralized wastewater treatment plants in Bangkok were designed as an activated sludge type biological nutrient removal that required energy for aeration. However, the wastewater flowed into WWPTs have insufficient organic carbon for nutrient degradation process that tends to have a low removal efficiency of nitrogen. The addition of carbon sources, are the preferred techniques for increasing the efficiency of wastewater treatment, however this adds more capital to the treatment method.

Solving this problem, the wastewater treatment plants by nature process, oxidation pond or stabilization pond, constructed wetland and plant filtration are simple low cost basic technology system. As they have become a favorable treatment system for treating domestic wastewater, especially in tropical zone. With it's ability to treat organic and nutrients that are polluted in domestic wastewater (Arceivala, 1973; Konnerup et al., 2009; Jinjaruk et al., 2014; Phewnil et al., 2014; LERD, 2015). In addition to the treatment of wastewater, the site of the system has also shown improvement towards to local ecosystem, thus taking advantage of these changes the LERD has become many tourist and agricultural attractions such as a bird watching area, feeding cattle, fish farming, sludge for glowing rice and aesthetics. (Chunkao et al., 2014; Dampin et al., 2012; Supakata and Chunkao, 2011)

4. Conclusion

Due to the lifestyle of the Thai people, domestic wastewater of Phetchaburi municipal and other cities in Thailand generally comprises of easily biodegradable organic matter and abundant of nutrients. Nitrogen and phosphorus also promotes biodegradation in both anaerobic and aerobic process. Consequently, the biodegradable organic compounds that were removed during transportation in sewer systems can concluded that the sewer system shows not only the collection and distribution of wastewater, but also a big reactor due to self-purification process.

The rapid decrease in BOD concentration during the delivering process from the city zone until the Klongyang collection pond was effected mainly due to both aerobic and anaerobic digestion process. Conceptually, dissloved particles does not only perform as an easily biodegradable organic matter, but also a favorable temperature that also promotes the rate of biochemical reaction while having the right ratio of carbon per nutrient. While only through the anaerobic digestion process under pressure are the conditions of the wastewater in the 18-km HDPE pipeline. The BOD digestion rate trend to constant at 12 km from the collection pond as total retention time is 35.2 hours in the sewer system, expanding in 1.2 hours from the point sources to the Klongyang collection pond, 29 hours in the collection pond and 5 hours in HDPE pipeline. Due to the slow decaying organic matter that is left over in the pipe, nutrients are not suitable for biological anarobic digestion where it's products inhibits further biodegradation process. The BOD in this process have been conducted with a 94.5% efficient for the Phetchaburi domestic wastewater. The generating of wastewater treatment system to treat with domestic wastewater are reduced due the transfer distance which promotes longer HRT and allows for longer digestion period as this resulted in the BOD loading to be reduce as it degraded the treatment capacity of the system.

In addition, wastewater treatment for general cities in Thailand should be adapted and utilize by nature process that consist of oxidation ponds, the vertical and horizontal flow through a constructed wetland. As through the process, not only to treat with organic compounds, total nitrogen and phosphorus and other indicators defined by Thai government to an under standard, but these systems can also be adapted to consist of advantages being a better ecosystem, feed cattle, fish farming, watering plants and aesthetic value as well.

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References

Arceivala SJ. Simple waste treatment method: aerated lagoons, oxidation ditches and stabilization ponds in warm and temperate climates. Publication no 44. Middle East Technical University, Ankara, Turkey. 1973.

Ashley RM, Hvitved-Jacobsen T and Bertrand-Krajewski JL. Quo vadis sewer process modelling? Water Science Technology 1999; 39(9): 9-22.

Aurelle Y. Treatments of oil-containing wastewater. Department of Sanitary Engineering, Chulalongkorn University, Thailand. nd.

Bangkok Metropolitan Administration (BMA). Bangkok State of the Enviroment 2012 (Revised Edition). Bangkok, Thailand. 2012.

Chernicharo CAL. Post-treatment options for the anaerobic treatment of domestic wastewater. Environmental Science and Bio/Technology 2006; 5: 73-92.

Chunkao K, Tarnchalanukit W, Prabuddham P, Phewnil O, Bualert S, Duangmal K, Pattamapitoon T and Nimpee C. H.M. The King's Royally Initiated LERD Project on community wastewater treatment through small wetland and oxidation pond in Phetchaburi, Thailand. Modern Applied Science 2014; 8(5): 233-46.

Dampin N, Tarnchalanukit W, Chunkao K and Maleewong M. Fish growth model for Nile tilapia (Oreochromis miloticus) in wastewater oxidation pond, Thailand. Procedia Environmental Sciences 2012; 13: 513-24.

Gryta M, Karakulski K and Morawski AW. Purification of oily wastewater by hybrid UF/MD. Water Research 2001; 35(15): 3665-69.

Henze M. Biological wastewater treatment: Principles modeling and design. IWA Publishing, London, UK. 2008.

Hvitved-Jacobsen T, Vollertsen J and Tanaka N. Wastewater quality changes during transport in sewers – An integrated aerobic and anaerobic model concept for carbon and sulfur microbial transformations. Water Science and Technology 1999; 38(10): 257-64.

Jensen NA. Empirical modelling of air-to-water oxygen transfer in gravity sewers. Water Environment Research 1995; 67(6): 979-91.

Jinjaruk T, Wararam W, Choeihom C and Srichomphu M. To study the wastewater treatment efficiency of Oxidation pond system in the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project. Annual report year 2014 on the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project (LERD), The Chaipattana Foundation, Thailand. 2014.

Konnerup D, Koottatep T and Brix H. Treatment of domestic wastewater in tropical, subsurface flow constructed wetlands planted with canna and Heliconia. Ecological Engineering 2009; 35: 248-57.

LERD. To study the wastewater treatment efficiency of oxidation pond system during 2009-2015 in the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project. Annual report year 2015 on the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project (LERD), The Chaipattana Foundation, Thailand. 2015.

Marchese J, Ochoa NA, Pagliero C and Almandoz C. Pilot-scale ultrafiltration of an emulsified oil wastewater. Environmental Science and Technology 2000; 34(14): 2990-96.

Metcalf and Eddy. Wastewater engineering treatment and reuse. 4th (ed.). McGraw-Hill, New York, USA. 2004.

Nielsen PH, Raunkjaer K, Norsker NH, Jensen NA and Hvitved-Jacobsen T. Transformation of wastewater in sewer system – a review. Water Science Technology 1992; 25(6): 17-31.

Noophan P, Paopuree P and Wantawin C. A study of nitrogen and phosphorus in various wastewaters in thailand. KKU Res J 2007; 12(3): 340-49.

Noophan P, Paopuree P, Kanlayaras K, Sirivethayapakorn S and Techkarnjanaruk S. Nitrogen removal efficiency at centralized domestic wastewater treatment plants in Bangkok, Thailand. EnvironmentalAsia 2009; 2: 30-35.

Orhon D, Ates E, Sozen S and Cokgor EU. Characterization and COD fractionation of domestic wastewater. Evnironmental Pollution 1997; 95(2): 191-204.

Pearce KN and Kinsella JE. Emulsifying properties of proteins: Evaluation of a turbidimetric technique. Agriculture and Food Chemistry 1978; 26(3): 716-23.

Phewnil O, Chunkao K, Pattamapitoon T, Intaraksa A, Chueawong O, Chantrasoon C and Boonprakong T. Choosing aquatic plant species of high wastewater treatment efficiency through small wetland. Modern Applied Science 2014; 8(4): 187-94.

Pollution Control Department (PCD), Ministry of Natural Resources and Environment. Thailand State of Pollution Report 2011. Bangkok, Thailand. 2012.

Poommai S, Chunkao K, Dumpin N, Boonmang S and Nimpee C. Determining the inpipe anaerobic processing distance before draining to oxidation pond of municipal wastewater treatment. Environmental Science and Development 2013; 4(2): 157-62.

Qteishat O, Ayszograj S and Suchowska-Kisielewicz M. Change of wastewater characteristic during transport in sewers. Waste Transactions on Environment and Development 2011; 11(7): 349-58.

Sawyer CN, McCarty PL and Parkin GF. Chemistry for environmental engineering and science. 5th(ed). McGraw-Hill, New York, USA. 2003.

Supakata N and Chunkao K. Thickness of moist sludge piling from community wastewater treatment through the Royal LERD technology for growing rice. Journal of Agricultural Science 2011; 3(3): 93-100.

Svoboda IF. Anaerobic digestion, storage, oligolysis, lime, heat and aerobic treatment of livestock manures. Final report of Provision of research and design ofpilot schemes to minimise livestock pollution to the water environment in Scotland QLC 9/2; 1-110. 2003.

Tsuzuki Y, Koottatep T, Jiawkok S and Saengpeng S. Municipal wastewater characteristics in Thailand and effect of “soft intervention” measures in household on polutant discharge reduction. Water Science and Technology 2010; 62(2): 231-44.