

# Nature of Solar Radiation as Encouraged to Produce an Increment of Dissolved Oxygen and Hydrogen Peroxide in Oxidation Ponds for Community Wastewater Treatment at H.M.The King's LERD Project Site in Phetchaburi Province, Thailand

Thanit Pattamapitoon<sup>1</sup>, Pramote Sirirote<sup>2</sup>, Pannee Pakkong<sup>3</sup> & Kasem Chunkao<sup>1</sup>

<sup>1</sup> Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok, Thailand

<sup>2</sup> Department of Microbiology, Faculty of Science, Kasetsart University, Bangkok, Thailand

<sup>3</sup> Department of Applied Radiation and Isotopes, Faculty of Science, Kasetsart University, Bangkok, Thailand

Correspondence: Thanit Pattamapitoon, Department of Environmental Science, Faculty of Environment, Kasetsart University, Bangkok 10900, Thailand. E-mail: thanit\_lerd@hotmail.com

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## Abstract

H.M.The King's initiative nature by nature process for community wastewater treatment has been conducted since 1990 at Laem Phak Bia sub district, Ban Laem district, Phetchaburi province, Thailand on UTM 1442240 to 1443480 N and 0619271 to 0619271 E. The fresh food markets and households were the point sources of Phetchaburi municipal wastewater that flowing newly construction sewage system in order to receive them to four sub stations on both sides of Phetchaburi river before pumping to Klonyang collection pond. The storage wastewater has been pumped about 3,600 cu.m./day through the 18.5 km. HPDE pipe and putting into sedimentation pond 1 and another four consecutive ponds (oxidation ponds 2, 3, 4, and 5) before the effluent flowing into the mangrove forest. However, the results of experiment found the values of BOD that showing drastic decreasing from Klonyang collection pond through the tip of 18.5 km. HPDE pipe to the sedimentation pond 1 then after it was gradually decreased from one oxidation pond to the next one. Highlight was placed on the obtained effluent after treated wastewater flowed over weir crest that finding BOD under standard and also the decreasing of total coliform bacteria and fecal coliform bacteria, particularly the pathogenic bacteria decreasing down to almost zero MPN/100mL. The question came up how total coliform bacteria and fecal coliform bacteria disappeared after the treated wastewater flowing over weir crest of the oxidation pond 3. The hypothesis was set on the effect of solar radiation to DO and H<sub>2</sub>O<sub>2</sub> which were employed for bacterial organic digestion process in wastewater treatment ponds by taking the measurement randomly on 19 May 2011 that solar radiation showing the solar energy between 0-750 W/m<sup>2</sup> all together with UV-A, UV-B, spectrum and net radiation.

In order to accomplish the objectives of study, the wastewater quality indicators were found BOD in sedimentation pond 1 67.5 mg/L and oxidation pond 3 16.6 mg/L for 13 hours measurement. In the same manner, the values of DO and H<sub>2</sub>O<sub>2</sub> for 13 hours measurement found in oxidation pond 3 greater than sedimentation pond 1 in respect to 8.9 and 7.6 mg/L for DO and 2.27 and 0.31 µg/L for H<sub>2</sub>O<sub>2</sub>. Moreover, the polynomial correlation was studied in order to determine the relationship between net radiation and DO and found very high correlation coefficients in both sedimentation pond 1 and oxidation pond 3. For the quantity of H<sub>2</sub>O<sub>2</sub>, it was obtained the relationship between net radiation and H<sub>2</sub>O<sub>2</sub> in higher correlation coefficient in sedimentation pond 1 than oxidation pond 3 because of smaller amount of dissolved organic and inorganic matters in oxidation pond 3. It would be the reason that oxygen which occurred from phytoplankton and algae photosynthesis were not employed by organic digestion and respiration of bacteria. Therefore, it had to exist DO and accumulation only in water instead of producing H<sub>2</sub>O<sub>2</sub> in oxidation pond 3 during daylight time. This is why H<sub>2</sub>O<sub>2</sub> in oxidation pond 3 was not varied directly to net radiation, and also causing an indication on the relationship between net radiation and H<sub>2</sub>O<sub>2</sub> in oxidation pond 3 lower than sedimentation pond 1. Summarily speaking, the nature of solar radiation plays vital role in encouraging producing DO and H<sub>2</sub>O<sub>2</sub> which are the important factors in bacterial organic digestion for community wastewater treatment with high efficiency.

**Keywords:** solar radiation, dissolved oxygen, hydrogen peroxide, oxidation pond, wastewater

## 1. Introduction

Accordance to H.M.The King has been royally initiative the nature by nature process for community wastewater treatment by utilizing oxidation ponds (as similar as lagoon and stabilization ponds) for obtaining free oxygen to sustain the bacterial organic digestion processing under supporting from three nature processes, they are photosynthesis, thermo siphon and thermo osmosis processes. Solar radiation plays the significant role in fulfillment of such three nature processes in order to produce DO by diffusing oxygen in vertical direction from the air to company with cooler wastewater on the surface because of using heat for evaporation (latent heat of evaporation approximately 583 gm-cal/gm-water) due to the thermo siphon process, while phytoplankton produces free dissolved oxygen in wastewater due to photosynthesis of phytoplankton and another floating aquatic plants and also due to thermo osmosis process by means on how oxygen in spongy cells (aerenchyma cells) of very young leaves during photosynthesis of phytoplankton and surrounding aquatic plants to produce oxygen with higher pressure enough to be forced passing through softer membrane to plant tissues and then to the root system (rhizosphere), finally contributing by diffusion process to bacteria in wastewater and soils as the energy sources for organic digestion. Consequently, the obtainable oxygen becomes to supply to bacteria for organic digestion in the said wastewater in order to receive better water quality after driving away of organic matters by oxidation pond wastewater treatment system. It's process includes five stages: firstly, wastewater product from fresh food markets, households, shopping areas, dessert factories, schools, government offices and cultural places; secondly, screening bigger size of organic wastes as well as skimming of oil and grease and also grit chamber for sand and gravel; thirdly, treatment of wastewater by wastewater treatment pond system (five ponds: sedimentation pond 1, oxidation pond 2, 3, 4 and 5) under the processes of bacterial digesting organic matters that are converted to become the inorganic materials as nutrients for the growth of phytoplankton and another types of aquatic plants in wastewater and its surroundings, following by keeping their photosynthesis processes in turn with producing DO as energy supply to bacteria for maintaining the endless organic digesting processes; fourthly, sedimentation of sludge during all time processing and fifth, effluent flow out to the public water sources by gravitational forces. In reality, effluent can be at more or less standards of water surface but it is very often to contaminate some diseases, only if they have to be killed by solar radiation, especially ultraviolet which is the most powerful energy. The phenomena like this normally occurs in the tropical zone with availability of solar energy in which Thailand is characterized for serving the above statement. With previous statement, H.M.The King has pushed an effort to initiate the project on how to treat the community wastewater under nature by nature processes in order to eliminate the contaminated organic wastes, toxic chemicals, oil and grease, color, bad smell gases and diseases which are the most dangerous microorganisms in community wastewater. Actually, the previous research did not find out the *Escherichia coli* (*E.coli*) in treated wastewater which was supposed to be killed in the effluent after flowing over the weir crest of third pond with retention time of 21 days, but it is still in doubt. However, it has been hypothesized that ultraviolet should be the most possible threads rather than something else.

Fundamentally, it is understood among scientists that solar radiation as the bio-conversion is presumable to stimulant plant in producing the  $H_2O_2$  by blue green algae (Cyanobacteria) under the photoautotrophic conditions should be special condition of its involvement for decreasing some bacteria species during bacterial organic digesting process one way and another. Naturally, incoming solar radiation to the earth surface is comprised of shortwave (wavelength less than 4  $\mu\text{m}$ ) and longwave (wavelength longer 4  $\mu\text{m}$ ) which are quantified as about 45% and 55%, respectively but they are depend on the sky conditions of the days and seasons of the years as the same as the location on the earth. Theoretically speaking, higher frequency is provided more heat due to more number of wavelength, that is why higher heat can be obtainable from x-rays and gamma rays (wavelength less 0.1  $\mu\text{m}$ ) and being gradual decreased consecutively ultraviolet (wavelength 0.1 to 0.38  $\mu\text{m}$ ), visible light (0.38 to 0.68  $\mu\text{m}$ ), near infrared (0.68 to 1.0  $\mu\text{m}$ ), far infrared (1.0 to 4.0  $\mu\text{m}$ ) and longwaves down to wavelengths of TV and radio as shown in Figure 1. Among those wavelengths, the visible light is normally called as shortwave down radiation which is about 45% of total radiation and composing of violet, indigo, blue, green, yellow, orange and red (VIBGAYOR) while ultraviolet (UV) is absorbed by ozone gas in the sky about 85% and the other 15% shortwave down radiation that functioning to control diseases not only contamination in air but also in wastewater for human beings.

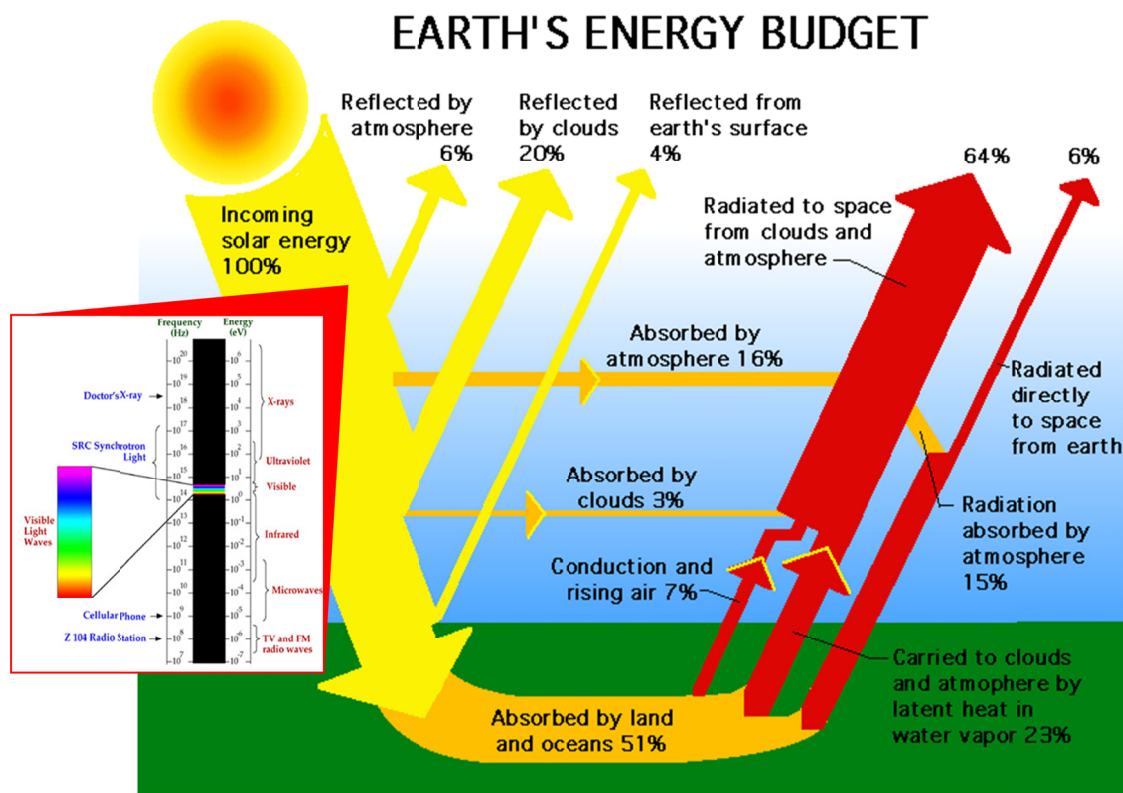


Figure 1. Hypothetical solar energy on the earth surface including UV, visible light and incoming and outgoing radiation (Source: Image courtesy NASA's ERBE (Earth Radiation Budget Experiment) program)

According to the oxidation pond system for wastewater treatment is relied on natural treating that wastewater begins to flow into the system in turn with screening of discarded food, skimming and grit chamber for settling sand and gravel by gravitational forces. Then, after the the treatment is started up by biological process with the support of solar radiation as the main energy source for stimulating on biochemical processes of living cells in order to cause an effect on aerobic process of organic digestion. In consequence, it makes the lowering of organic matters and dissolved oxygen (William et al., 1852; Tapas, 2001; Macos, 2005). However, when wastewater was accomplished the treatment process and flew to the polishing pond, the treated wastewater indicators chemical oxygen demand (COD), biological oxygen demand (BOD), total dissolved solid (TDS) and total coliform bacteria (TCB) were lowered down to the standard of effluent as set by the Ministry of Natural Resource and Environment. In contrary, the value of DO was additionally increased because of the photosynthesis processes of algae and phytoplankton together with thermo osmosis and thermo siphon processes and also wind blow (Richard et al., 1995; Donat et al., 1997; Leena et al., 2011; Chunkao et al., 2012).

Lowering and adding of DO will be influenced to free radical occurrence in wastewater (Volodymyr, 2011) which causes the break down of oxygen molecules by solar radiation at the wavelength of visible light, UV-A and UV-B which are the catalyst of chemical reaction (John et al., 1998; Gerringa et al., 2004; Steven et al., 2010). In consequence, the outcome obtained so many free radical forms such as hydrogen peroxide ( $H_2O_2$ ), hydroxyl radicals ( $OH^*$ ) and superoxide anion ( $O_2^*$ ) but they were found out more potentials and severely specific oxidizing property and named as  $H_2O_2$  (Robert & Gambini, 1990) by means of  $H_2O_2$  that being oxidized in both the organic and inorganic substances which are contaminated in wastewater will be transformed into COD, BOD, TDS and bad smell (Alenka et al., 2006; Mohamed, 2006; Roberto et al., 2009; Zulfikar et al., 2011). It is the highlight of this transformation of organic and inorganic substances that results the decrease of humic substances in wastewater which are the major organic constituents to be able to make the water in black color (Gen et al., 2001). Besides,  $H_2O_2$  is competent to kill Cyanobacteria and to devastate microcystin structure which is the toxic substance and produced by Cyanobacteria (Rui et al., 2005; Dani et al., 2012), just like *E.coli*, which is pathogenic bacteria to have severe diarrhea and important indicator for community wastewater quality, has to be killed one way or another (Davies et al., 1997; Asad et al., 1998) by running into cell in order to damage to mitochondria and DNA of *E.coli*

causing death in consequence (Yoel et al., 1987; Richard et al., 2003). Moreover, the concentration of  $H_2O_2$  between 0.2-0.3 mM. can be incompetent to suppress the disease occurrence of *E.coli* (Hegde et al., 2008) but  $H_2O_2$  cannot do any damage to zooplankton, small and big marine fishes (Dani et al., 2012; Hans et al., 2012). It could be presumed that the above statement pointed out the shortwave length of visible light, particularly UV, is the catalyst to stimulate the chemical reaction which might produce some quantity of DO and  $H_2O_2$  to decrease not only organic and inorganic substances but they are also competent to kill pathogenic bacteria and *E.coli* in Phetchaburi municipal wastewater. Therefore, it is very necessary to study on the role of solar radiation in relation to produce the quantity of DO and  $H_2O_2$  in H.M.The King's initiative nature by nature process for Phetchaburi municipal wastewater treatment system in order to know the involved factors and their mechanisms to decrease COD, BOD, TDS and pathogenic bacteria to be under standard of treated wastewater before draining to the public water sources.

## 2. Location of the Royal LERD Project Site

H.M.The King's initiative nature by nature process on Laem Phak Bia Environmental Research and Development project (Royal LERD Project) at Laem Phak Bia sub district, Ban Laem district, Phetchaburi province, Thailand between latitude  $130^{\circ} 02'40''$  to  $130^{\circ} 03'20''N$  and longitude  $1000^{\circ} 05'10''$  to  $1000^{\circ} 05'10''E$ , or UTM at 1442240 N to 1443480 N and 0617780 to 0619271 E, approximately 122 km. from Bangkok to the south (Figure 2). Actually, the project site is far from the city of Phetchaburi (Phetchaburi municipal) about 12 km., which is composed of local people 40,000 persons plus tourists and illegal workers about 10,000 persons/day. The coverage area is about 260 hectares which localizes inside the natural mangrove forest as laid down from Phetchaburi province to Bangkok (Phetchaburi-Bangkok mangrove forest) with the length of about 140 km. and the width (seashore to inland side of mangrove forest about 2 km.). Geographical location, the east side adjoins to the Gulf of Thailand, the north to Phetchaburi-Bangkok mangrove forest plus mud beach, the south to the mangrove forest patch nearby well known Hat Chao Sumran sand beach, and the west close to Wat Samutkodom (Buddhist temple) as belonged to Ban Phanern village.

In fact, the study areas are composed of not only the Royal LERD project site at Laem Phak Bia but also including the whole area of Phetchaburi municipal as point sources of community wastewater producing approximately 7,000 cu.m./day. However, the modification of sewage drainage system in town was taken care for holding back wastewater instead of direct flowing to Phetchaburi river but turning back by lifting up the pipe ends to the collection culverts to the four sub pumping stations then pumping them to the main collection pumping station at Klongyang village. For implementation, Phetchaburi municipal wastewater at Klongyang collection wastewater station has to pump continuously through 18.5 km HPDE pipe to the Royal LERD project site about 3,600 cu.m./day to treat at the first pond (sedimentation pond 1), to the second pond (oxidation pond 2), the third pond (oxidation pond 3), the fourth pond (oxidation pond 4) and the fifth pond (oxidation pond 5) for community wastewater treatment as illustrated in Figure 2. In addition, all 5 ponds wastewater treatment system is laid down in the open air without interruption of sunshine and blow in wind in order to promote photosynthesis of algae and pond evaporation for producing an effect of both the thermo siphon and thermo osmosis processes to add up free oxygen in wastewater for bacterial organic digestion process

## 3. Methods and Procedure

### 3.1 Solar Radiation Measurement

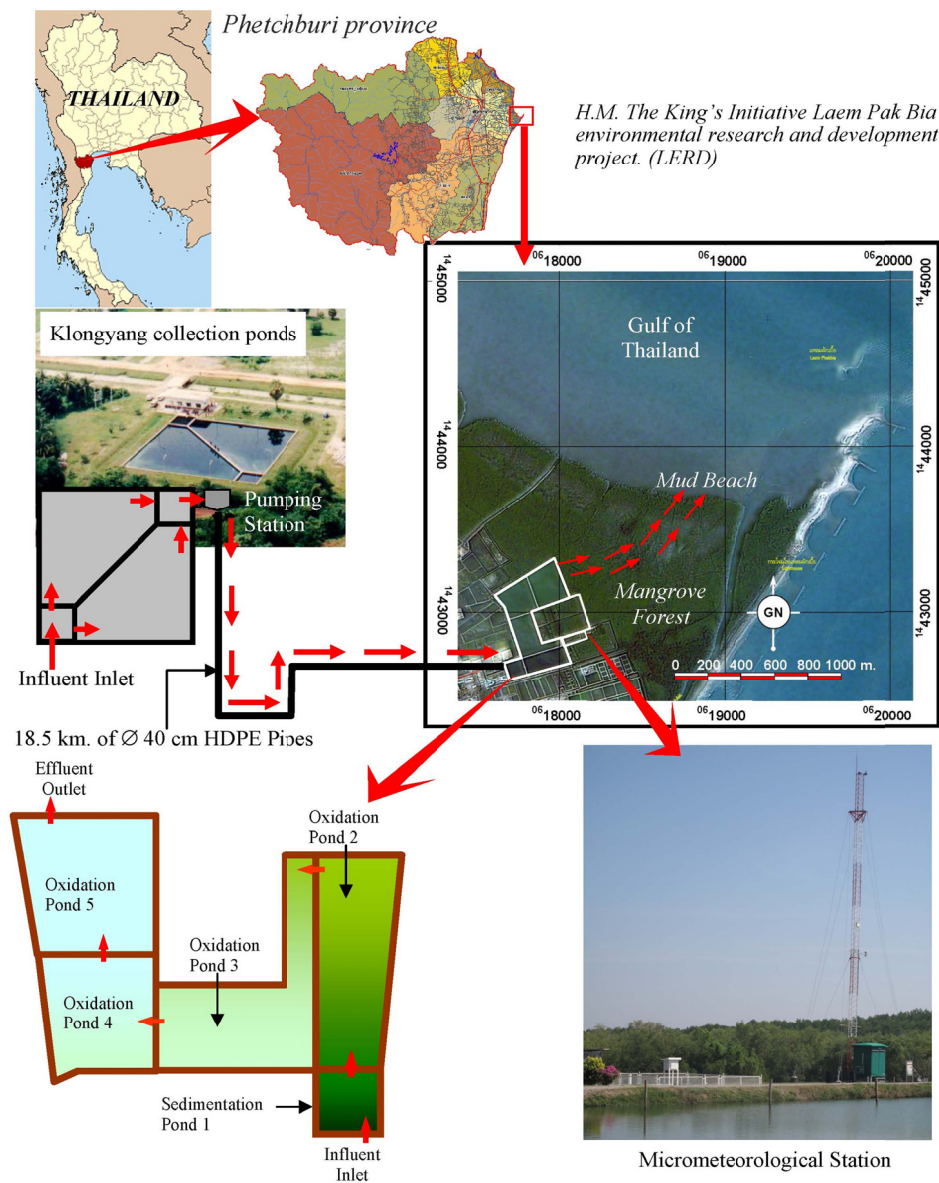
The 40 m height of micrometeorological tower has been settled down at the east corner of the Royal LERD project site (Figure 2) for measuring the incoming shortwave radiation ( $R_{sd}$ ), outgoing short wave radiation ( $R_{su}$ ), incoming long wave radiation ( $R_{ld}$ ), outgoing long wave radiation ( $R_{lu}$ ), net radiation ( $R_n$ ), ultraviolet, spectrum (VIBGYOR), near infrared and also taking the Royal LERD climatic station to measure the daily rainfall, air temperature, relative humidity, pan evaporation, wind speed and direction and sunshine period. Data collection will be analyzed in daily basis in order to serve needs of any experiment that concerning with H.M.The King's initiative nature by nature process on community wastewater treatment and garbage disposal.

### 3.2 Wastewater Quality Sampling

According to investigate the influences of net radiation to add up the DO and  $H_2O_2$  in wastewater, therefore the blue sky day of 19 May 2011 will be selected as the representative for searching the relationship between total radiation to the occurrences of DO and  $H_2O_2$  in wastewater. In the same manner, the sampling points have been fixed at the middle of sedimentation pond 1 and oxidation pond 3. Water samples were taken at 30 cm. depth by PE bottles every one hour during 06:00 to 19:00 o'clock.

### 3.3 Wastewater Quality Analysis

An application of APHA AWWA and WPCF (1995) was conducted to determine pH, temperature, DO, BOD and total bacteria count. In addition, H<sub>2</sub>O<sub>2</sub> concentration was determined by titration methods (Solvay, 2004). The followings are details of chemical analysis: thermometer for water temperature; pH meter for pH; azide modification for DO; azide modification 5 day 20 °C for BOD and dilution plate count for total bacteria.



	Sedimentation Pond 1	Oxidation Pond 2	Oxidation Pond 3	Oxidation Pond 4	Oxidation Pond 5	Total
Dept. (m.)	2.3	2	1.9	1.8	1.7	-
Area. (sq. m.)	10,217.00	20,408.00	24,898.00	35,424.00	43,131.50	154,178.50
Capacity (cu.m.)	23,499.10	60,816.00	66,306.20	63,763.20	73,323.50	287,708.00

Figure 2. Location of the Royal LERD project site at Laem Phak Bia sub district, Ban Laem district, Phetchaburi province, including Phetchaburi municipal wastewater, Klonyang collection pond, pumping station, 18.5 km. HPDE pipe, five pond for wastewater treatment, micrometeorological tower for solar radiation measurement and climatic station

## 4. Results and Discussion

Due to the objective is to study on nature of solar radiation as the stimulant for producing the increment of DO and H<sub>2</sub>O<sub>2</sub> in community (Phetchaburi municipal) wastewater on which they are referred to kill some pathogenic bacteria during sunshine period of the day. The analyzed results will be presented as follows:

### 4.1 Quantitative Phetchaburi Municipal Wastewater

Before the year of 1990, the sewage was directly drained into the Phetchaburi river that causing stream water in unpleasant color and smell. Water in Phetchaburi river was constraint to use for day to day lifestyle, waterworks, aquatic lives and maintaining the local cultural activities. Therefore, the Phetchaburi river water was really needed to take in conservation measures in order to recover for serving any purposes as it used to be. As stated in the previous sections, the Phetchaburi municipal has been composed of fully growth of population approximately 40,000 persons plus another 10,000 tourists, which produces community wastewater about 7,000 cu.m./day. This amount of community wastewater has been forced by redesigning sewage drainage system for turning back to main culverts that being parallel along the riverbanks before pumping to Klonyang collection pond. Only 3,600 cu.m./day can be pumped from Klonyang collection pond under the anaerobic digestion processes flowing through the 18.5 km. HPDE pipe in order to transferring to the designing treatment capacity of 10,000 cu.m./day by starting up on the sedimentation pond 1 and another 4 consecutive ponds as called oxidation pond system. In order to maintain the aquatic ecological balancing in wastewater treatment pond system, the three herbivore fishes/sq.m. have been allowed into every treatment pond for controlling the blooming of phytoplankton and another algae species due to higher concentration of nitrogen and phosphorus as the products of bacterial organic digestion processes in wastewater treatment pond system.

### 4.2 Wastewater Quality in Treatment Pond System

The previous investigation of the Royal LERD project found that fresh food market and households were the main point sources of Phetchaburi municipal wastewater flowing directly to the river of Phetchaburi and producing organic wastes in form of BOD more than 500 mg/L (COD exceeding 1,200 mg/L) and rapidly decreased down more or less 200 mg/L (ranging between 150 to 300 mg/L, depending on season of the year) in the drainage system, and next to the collection pond at Klonyang pumping station, at the sedimentation pond 1 after flowing through about 80 mg/L (ranging between 50 to 120 mg/L), and finally effluent at the oxidation pond 5 less 10 mg/L (some occasion almost attaching to the effluent standard 20 mg/L). In addition, the Royal LERD research result was shown that the wastewater in sedimentation pond 1 and oxidation ponds were found high density of the water born diseases in group of *E.coli* but very low number. The total perspective of decreasing organic matters according to aerobic and anaerobic processes from fresh food markets and households as the main point sources of Phetchaburi municipal through culverts plus pipes sewage systems, Klonyang collection pond, 18.5 km. pipes, 5 consecutive wastewater treatment ponds, natural mangrove forest as the second wastewater treatment units and Bangkok-Phetchaburi mud beach in part of Phetchaburi province has been illustrated in Table 1.

The drastic decrease of organic wastes in wastewater in terms of BOD and some other indicators are shown in Table 1 due to the fact that the longer degradation period of dissolved organic matters (mostly DOC, DOP, DON and DOS) were completely separable from the solid wastes under both aerobic and anaerobic processes in hot and humid tropical climate of Phetchaburi municipal, particularly from point sources at fresh food markets and households from 546.6 mg/L to 162.7 mg/L (e.g. BOD 70% decreasing) through long and 90 percentage closed sewage drainage system the prior wastewater receiver of Klonyang collection pond from 162.7 mg/L to 79.5 mg/L (e.g. BOD 50% decreasing) and then after pumping through 18.5 km. HPDE pipe (e.g. BOD 46% decreasing), and causing BOD as influent to sedimentation pond 1 from 79.5 mg/L to 43.7 mg/L (e.g. BOD 45% BOD decreasing). After moving through the 5 treatment ponds, the obtained BOD from influent 43.7 mg/L to the effluent 23.0 mg/L (e.g. BOD 47% decreasing), and finally the measured values of 2.5, 2.2 and 2.5 mg/L in natural mangrove forest, mud beach and seashore, respectively (Table 1). It is remarkable to point out that the bacterial digestion processes (both aerobic and anaerobic processes) as the path way of Phetchaburi municipal wastewater treatment system were shown an effectiveness of H.M.The King's initiative nature by nature process without any doubt for Maintainability of sustainable marine water quality. However, the research results also found TDS, TSS, TKN, phosphate, nitrate and total coliform bacteria but opposite direction indicating on COD and pH because of the influences of marine water.

Intensive consideration is placed on an increase of DO in Phetchaburi municipal wastewater which found 0.9 mg/L at the fresh food markets and households 1.0 mg/L at sewage drainage system, 1.0 mg/L at Klonyang collection pond, 1.4 mg/L at the end of 18.5 km. HPDE pipe, effluent DO 7.6 mg/L at the outlet of 5 treatment ponds, 6.0, 5.9, and 6.0 mg/L in the mangrove forest, mud beach, and seashore, respectively. It would be assured the values of DO

in the sea water for supplying to bacteria organic digestion processing that causing the drastic decreasing of BOD, TDS, TSS, TKN, Phosphate and Nitrate. Surprisingly, the total coliform bacteria found very high numbers of  $7.9 \times 10^6$  MPN/100mL in Klongyang collection pond and  $3.9 \times 10^6$  MPN/100mL but the drastic decreasing by indicating the measured value only  $1.7 \times 10^2$  MPN/100mL after passing through 5 treatment ponds of the Royal LERD project. In addition, the existence of total coliform bacteria was accepted to carry in mangrove forest for 9.0 MPN/100mL, in mud beach 11.0 MPN/100mL and in the seashore less 1.8 MPN/100mL, respectively (Table 1).

Table 1. Representatives of wastewater quality indicators as measured at Phetchaburi municipal point sources on fresh market and households, sewage system, Klongyang collection pond, 18.5 pipes, 5 consecutive community wastewater treatment ponds, mangrove forest, mud beach and seashore as conducted during August to October 2010 for about 80 hr. traveling time

Measuring point	Wastewater Quality Indicators									
	pH (-)	TDS (mg/L)	TSS (mg/L)	DO (mg/L)	BOD (mg/L)	COD (mg/L)	TKN (mg/L)	NO <sub>3</sub> <sup>-</sup> (mg/L)	PO <sub>4</sub> <sup>3-</sup> (mg/L)	Coliform Bacteria (MPN/100mL)
Fresh Food Markets and Households	6.8	2,761.90	1,127.00	0.9	546.6	1,156.00	14.6	0.7	25	-
Sewage Drainage System	7.8	462	100.2	1	162.7	242.9	15.3	0.2	4.1	-
Klongyang Collection Pond	6.2	410	27	1	79.5	96	14.6	0.6	1.9	$7.9 \times 10^6$
18.5 km. Pipe	7.1	480	35.9	1.4	43.7	95.2	14.1	0.6	1.6	$3.9 \times 10^6$
5-Treatment Pond (WTP)	8.8	674	105	7.6	23	96	3.6	0.7	0.2	$1.7 \times 10^2$
Mangrove Forest	8	32,032.00	138	6	2.5	922	3.8	0.1	0.1	9
Mud Beach	8	31,424.00	165	5.9	2.2	984	4	0.1	0.2	11
Seashore	8	32,784.00	196	6.2	2.5	1,055.00	3.8	0.1	0.22	<1.8

#### 4.3 Appropriate Numbering of Oxidation Treatment Ponds

In practical point of view, the Royal LERD project has constructed 5 treatment ponds for conducting Phetchaburi municipal wastewater treatment as transported from Phetchaburi municipal about 18.5 km by HPDE pipes as mentioned the previous sections. In terms of economic purpose, if possible, it should take only 3 rather than 5 treatment ponds. However, an observation on 20 year study indicated that the flowing wastewater over weir crest of oxidation pond 3 found the effluent under surface water quality standards as shown in Figure 3, on which the most probable numbering has been placed on the first pond (sedimentation pond 1), the second pond (oxidation pond 2), and the third pond (oxidation pond 3). It is shown the effectiveness of the drastic decreasing on effluent of treated wastewater quality on BOD, TKN, and coliform bacteria, while DO has the increasing tendency which are followed the bacterial organic digestion principles and going hand in hand with availability of marine water to act both the dilution and adding some chemical compounds to such treated wastewater effluent.

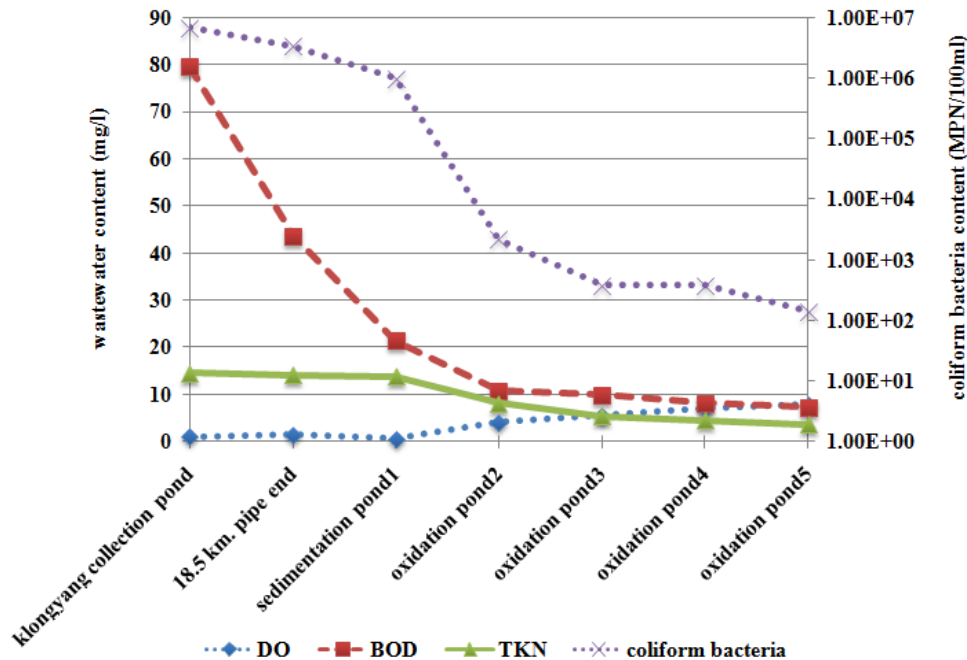


Figure 3. Effluent quality indicators of Phetchaburi municipal wastewater transporting from tip of 18.5 km. HPDE pipe through sedimentation pond 1, oxidation ponds 2, 3, 4 and to final oxidation pond 5 as measured continuously 24 times of sampling (except coliform bacteria only 6 times of sampling) for one year period by beginning on 28 December 1999 to 28 August 2000 as the phenomena representatives

It would be expressed that the treatment efficiency of 3 ponds (sedimentation pond 1, oxidation ponds 2 and oxidation pond 3) as belonged to the Royal LERD project have shown only the decreasing of organic wastes and also to eradicate the total coliform bacteria. Moreover, there is no finding the *E.coli* and another pathogenic bacteria after the wastewater body flowing over the weir crest of the oxidation pond 3 which was investigated by the Department of Medical Science, Ministry of Public Health, Thailand. This mean that whenever the community wastewater treatment has been taken by the 3 ponds system with HRT approximately 21 days, the obtained treated wastewater should be surely clean enough not only decreasing organic matters of both the solid and liquid forms, but also to eradicate pathogenic bacteria in Phetchaburi municipal wastewater without doubtfulness. Seasonal variation of bacteria count was considered to show the drastic change among outlets of treating units as illustrated in Table 2 and Figure 4. Results indicated drastically decreasing in the summer time from the Klongyang collection pond through the 18.5 km. at sedimentation pond 1 for total coliform bacteria and oxidation pond 3 for fecal coliform bacteria. The reason could be pointed out that both facultative bacteria (total coliform bacteria and fecal coliform bacteria) needed oxygen for survival but it was very less in the sewage system as the same as in higher concentration of organic content of Klongyang collection pond and also no oxygen in the 18.5 km pipe. When both the total coliform bacteria and fecal coliform bacteria were flown out to contact at sedimentation pond 1 with higher concentration of organic content but less dissolved oxygen that recovered oxygen causing survival of total coliform bacteria but still decreasing fecal coliform bacteria due to not being enough oxygen for their living. It would be remarkable that the drastic decreasing in rainy and winter season showed the same trends as in summer time on both the total coliform bacteria and fecal coliform bacteria. Due to high concentration of organic matters in Phetchaburi community wastewater, the drastic decreases were indicated at the oxidation pond 3 for both the total coliform bacteria and fecal coliform bacteria.



Table 2. Seasonal variation of bacteria count effluent (treated wastewater) from Klongyang collection pond, through tip of 18.5 km. HDPE pipe and 5 treatment ponds

Date	Type of Coliform Bacteria	Bacteria Count (MPN/100mL)						
		Klongyang Collection pond	18.5 km HDPE Pipe	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5
10 May 2007 (Summer)	Total	200,000	16,000	9,200	130	22	33	23
	Fecal	20,000	2,700	140	11	7	11	2
15 Aug 2007 (Rainy)	Total	120,000	14,000	280	130	1,000	140	350
	Fecal	90,000	1,300	180	79	350	79	130
12 Dec 2007 (Winter)	Total	2,300,000	500,000	8,000	16,000	9,200	3,500	28,000
	Fecal	800,000	200,000	5,000	170	54	170	120

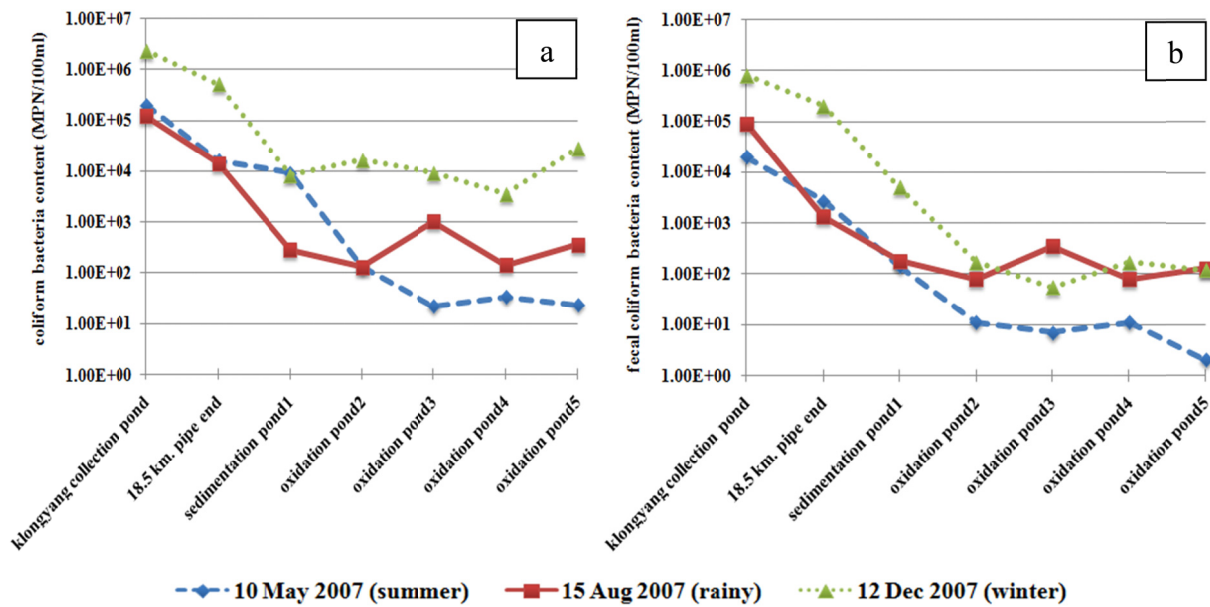


Figure 4. Seasonal variation of total coliform bacteria and fecal coliform bacteria as measured in summer season, rainy season and winter; (a) total coliform bacteria and (b) fecal coliform bacteria

4.4 Quantitative Solar Energy Measurement

Owing to the disappearance of *E.coli* was discovered in treated wastewater after overflowing the weir crest of oxidation pond 3 which took 21 days for hydraulic retention time (HRT) since the first drop going in the sedimentation pond 1 as mentioned in previous section. The cause of *E.coli* death was hypothesized on the ultraviolet radiation (UVR) and all wavelength of spectrum, therefore the measurement of solar energy was conducted at the Royal LERD experimental area. Unfortunately, the instrument can measure only UV-A and UV-B, not for UV-C measuring but primary evaluation can be taken in relation to the disappearance of *E.coli* after overflowing the oxidation pond 3 weir crest before moving into the oxidation pond 4. However, the measuring solar energy on the spectrum (violet, indigo, blue, green, yellow, orange, and red), UV-B and UV-A were shown in Figure 5a, while the energy balance also measured on net radiation (Rn), incoming shortwave radiation (Rsd) and incoming longwave radiation (Rld) as seen Figure 5b. The relationship can be expressed as  $R_n = R_{sd} - R_{su} + R_{ld} - R_{lu}$ . Natural point of view, Rn is supposed to use for latent heat flux (LE), sensible heat flux (H), soil heat flux (G), photosynthesis (Ph), metabolism (M), and chemical reaction (C) which can be written as  $R_n = LE + H + G + Ph + M + C$ . However, all above statements play a significant role in the death of *E.coli* after wastewater flowing over the weir crest of sedimentation pond 1 oxidation pond 2 and oxidation pond 3. It is a matter of fact, the Royal LERD project

area is located on the open uniform site, therefore the effects of blockage due to surrounding trees and buildings can be ignored for consideration on solar energy.

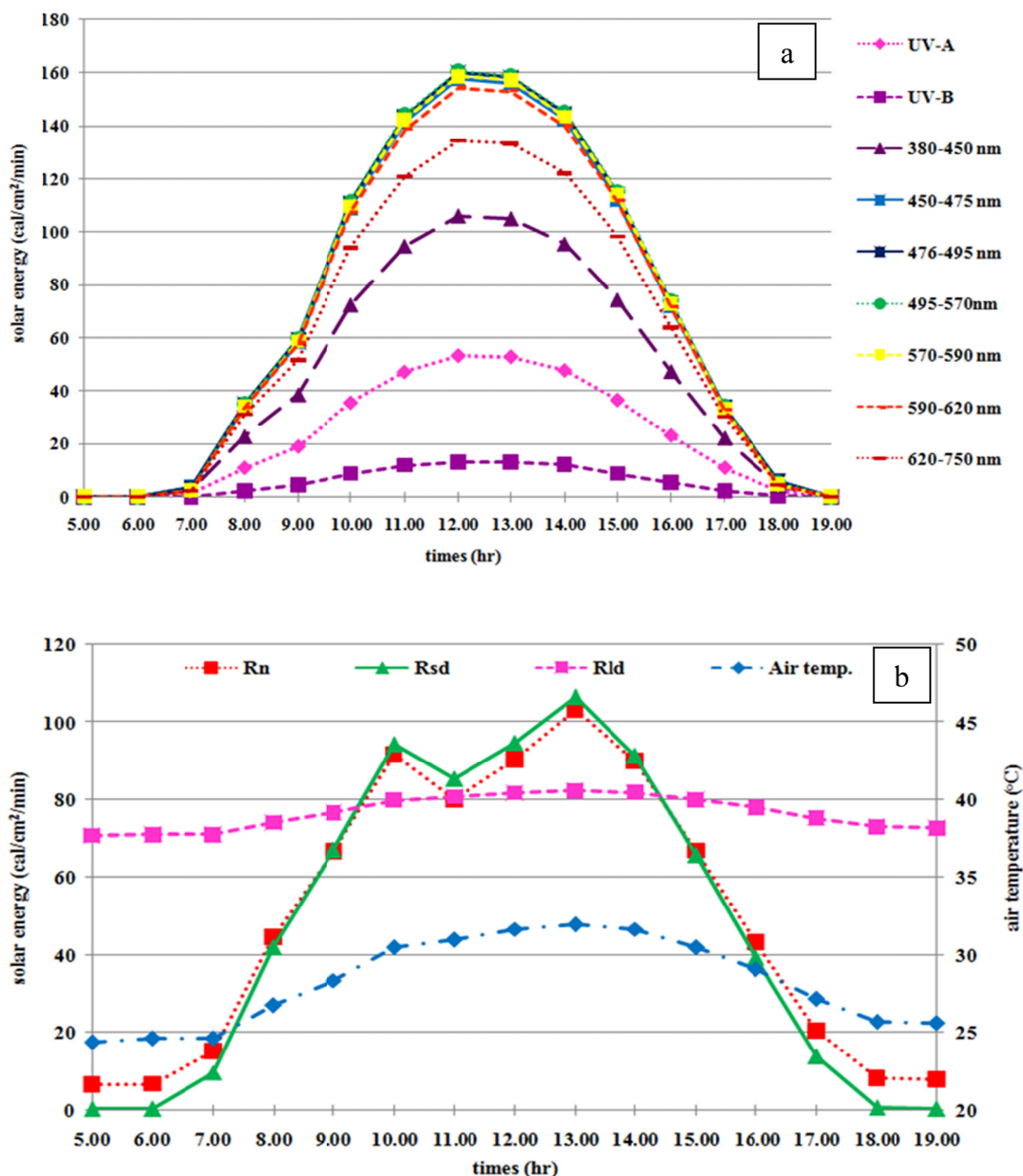


Figure 5. UV-A, UV-B and Spectrum (a) and energy balance (b) of the Royal project site in Phetchaburi province

Results of measuring UV-A, UV-B and spectrum (violet, indigo, blue, green, yellow, orange, and red) and also energy balance were shown in Figures 5a and 5b in which the UV-A, UV-B and spectrum begin to shine after 06:00 a.m. and maximizing about noon. In the same behavior, the heat energy is gradually increased to the peak, and then decreasing down to about 07:00 p.m., in turn to the increasing in heat enough to affect on the increment of DO and H<sub>2</sub>O<sub>2</sub> for encouraging the bacterial organic digestion processes.

#### 4.5 Water Quality in Wastewater Treatment System

First of all, the measurement of the concerned water quality indicators was randomly conducted on the whole day of 19 May 2011, the results as shown in Table 3. It would be noted that this experiment was taken in total bacteria as the representative of *E.coli* which occurs directly from human.

Table 3. Some concerned water quality indicators as measured on the 19 May 2011 at the sedimentation pond 1 and oxidation pond 3

Times	Sedimentation Pond 1					Oxidation pond 3				
	Temp (°C)	pH (-)	DO (mg/L)	BOD (mg/L)	Total Bacteria (CFU/mL)	Temp (°C)	pH (-)	DO (mg/L)	BOD (mg/L)	Total Bacteria (CFU/mL)
06.00	29.2	6.9	1.2	116.0	$1.8 \times 10^8$	29.8	6.8	2.5	5.3	$1.0 \times 10^6$
07.00	29.4	6.9	1.4	118.0	$5.0 \times 10^6$	29.9	7.0	2.5	1.3	$1.0 \times 10^4$
08.00	30.4	6.9	2.2	120.0	$7.3 \times 10^7$	30.3	7.0	5.0	3.6	$2.0 \times 10^5$
09.00	30.6	7.0	2.1	130.0	$3.4 \times 10^8$	30.4	7.1	4.7	6.0	$4.0 \times 10^6$
10.00	31.6	7.2	4.1	136.0	$1.7 \times 10^8$	31.5	7.5	6.9	20.6	$8.0 \times 10^4$
11.00	33.1	7.4	7.7	36.5	$4.7 \times 10^8$	32.4	7.6	9.3	19.6	$8.0 \times 10^4$
12.00	34.3	7.6	11.9	35.5	$1.4 \times 10^8$	32.9	7.8	10.7	21.0	$1.3 \times 10^2$
13.00	34.3	7.8	13.1	36.5	$3.2 \times 10^8$	32.3	8.0	10.9	23.6	$1.0 \times 10^4$
14.00	33.8	7.8	13.6	39.5	$2.5 \times 10^8$	32.9	8.0	14.1	23.0	$2.0 \times 10^6$
15.00	34.0	8.0	15.3	39.0	$1.4 \times 10^8$	32.4	8.0	13.9	24.6	$2.0 \times 10^4$
16.00	33.7	8.0	15.1	30.0	$6.2 \times 10^8$	32.1	7.9	12.6	22.6	$2.0 \times 10^6$
17.00	32.7	7.7	9.5	33.5	$4.2 \times 10^8$	32.1	7.6	12.3	21.3	$1.7 \times 10^2$
18.00	32.1	7.9	8.4	37.0	$3.3 \times 10^8$	31.7	8.0	11.2	19.3	$3.0 \times 10^4$
19.00	31.0	8.0	1.3	37.5	$4.1 \times 10^8$	31.7	8.2	9.3	20.6	$1.0 \times 10^4$
Average	31.7	7.5	7.6	67.5	$2.7 \times 10^8$	31.3	7.6	8.9	16.6	$6.7 \times 10^5$

The values of BOD in sedimentation pond 1 was ranged between 116.0-136.0 mg/L during 06:00 a.m. to 10:00 a.m. because of heavy cooler water surface sinking downward to the bottom of the pond that forcing the sediment going up to the surface (under the thermo siphon process), then the aerobic bacteria with the high amount of  $10^6$  to  $10^8$  CFU/mL which functioned as electron acceptors to digest the organic matters (Cloete et al., 1983). Until 11:00 a.m., the full sunshine was appeared and caused solar energy functioning for photosynthesis of phytoplankton to produce more DO and meeting the maximum at 03:00 p.m., and resulting DO increasing to 15.3 mg/L which was enough for bacteria to employ as the electron acceptor in the organic digestion process that decreasing BOD down between 30.0-39.5 mg/L. Water quality in oxidation pond 3 found temperature 29.8-32.9 °C, pH 6.8-8.0, DO 2.5-14.1 mg/L and BOD 1.3-24.6 mg/L, while the DO was low value of 2.5-5.0mg/L during 06:00 a.m. to 09:00 a.m. but BOD became low only 1.3-6.0 mg/L because of DO was not employed as electron acceptors by aerobes in organic digestion processes in which it would be harmonized with the study on the efficiency of aerobic bacteria organic digestion that employing oxygen as electron acceptor. However, it was discovered that the appropriate quantity of DO for aerobic bacteria organic digestion with using oxygen as electron acceptor could be occurred during DO ranging between 4.0-8.0 mg/L (Taylor et al., 2009). Therefore, time between 10:00 a.m. to 07:00 p.m. of each day should be the period of increased DO values between 6.9-14.1 mg/L which was the appropriate quantity for aerobic bacteria that employing oxygen as electron acceptor to enhance the activities of organic digestion processing, affecting an increasing of organic content in form of BOD.

#### 4.6 Quantity of Dissolved Oxygen in Wastewater Treatment System

The measurement of water quality in sedimentation pond 1 resulted DO 1.2 mg/L on 06:00 a.m. and trending to increase in maximum values of 15.3 mg/L on 03:00 p.m. (averaged producing rate 1.5 mg/L/hr) but the DO quantity was rapidly decreased from 15.3 mg/L down to 1.3 mg/L at the period between after 03:00 p.m. to 07:00 p.m. (averaged decreasing rate 3.5 mg/L/hr). In contrary, DO in oxidation pond 3 was found rapid increase from 2.5 mg/L on 06:00 a.m. to 14.1 mg/L on 02:00 p.m. (averaged producing 1.4 mg/L/hr), after 02:00 p.m. DO decreasing from 14.1 mg/L down to 9.3 mg/L on 07:00 p.m. (averaged decreasing rate 0.9 mg/L/hr) as shown in Figure 6.

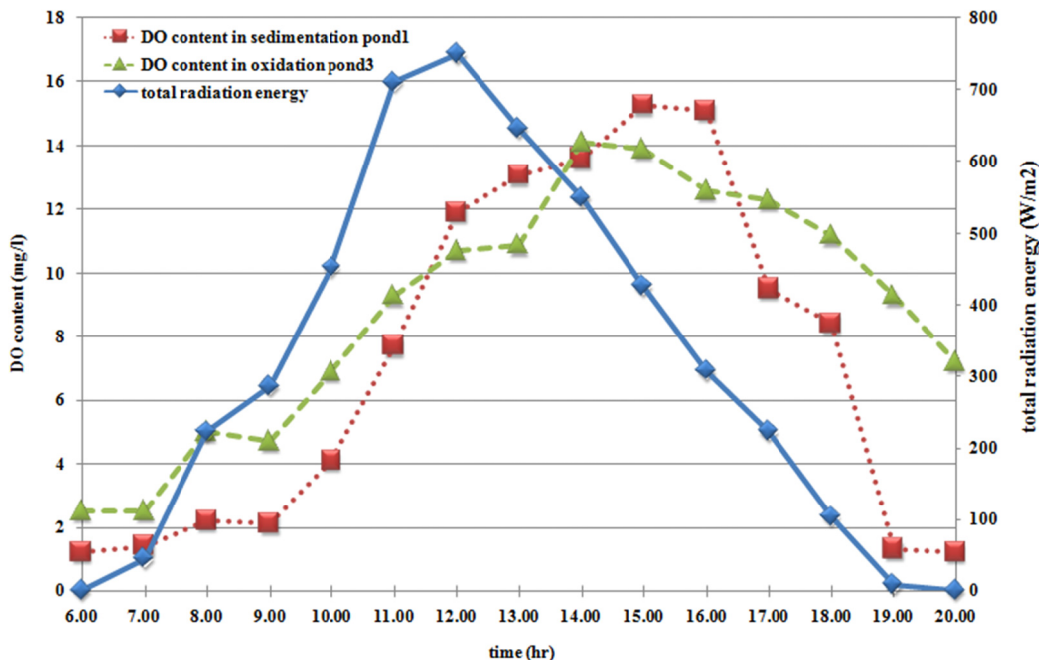
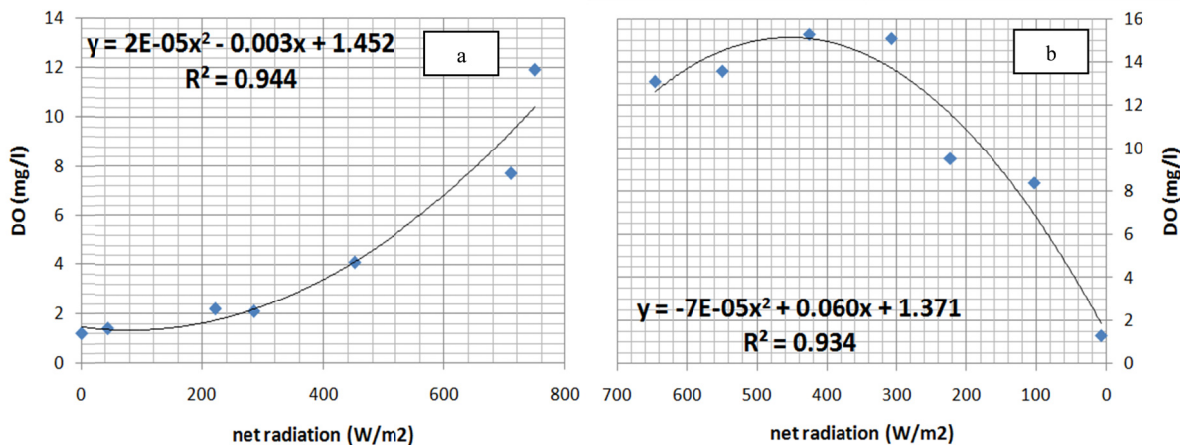


Figure 6. Distribution of DO in wastewater treatment ponds for Phetchaburi municipal wastewater treatment at the Royal LERD project site at Laem Phak Bia sub district, Ban Laem district, Phetchaburi province, Thailand

From Figure 6, quantity of DO in sedimentation pond 1 and oxidation pond 3 were consisted of very close producing rates, i.e., 1.5 mg/L and 1.4 mg/L, respectively. So that, they were resulted from photosynthesis of abundant phytoplankton of both ponds. It is evident since after 12:00 a.m. that DO in sedimentation pond 1 and oxidation pond 3 were decreased due to be employed for electron acceptors in the respiration process (Cloete et al., 1983), but the decreasing rate of DO in sedimentation pond 1 was faster rate than oxidation pond 3, i.e. 3.5 mg/L/hr and 0.9 mg/L/hr, respectively because of more bacteria. In order to insist this statement, the water samples were analyzed the total bacteria in sedimentation pond1 found out ranging between  $10^6$  to  $10^8$  CFU/mL, while the oxidation pond 3 found the total bacteria ranging between  $10^2$  to  $10^6$  CFU/mL as shown in Table 3. For making clear understanding, the polynomial correlation was studied on the relationship between solar energy and DO of sedimentation pond 1 and oxidation pond 3 for two periods in the morning (06:00-12:00 a.m.) and in the afternoon (01:00-07:00 p.m.). The results of the correlation coefficient ( $R^2$ ) of sedimentation pond 1 in the morning found 0.944 and in the afternoon 0.934, and also for oxidation pond 3 findings of 0.983 in the morning period and 0.8252 in the afternoon, on which they were shown very high correlation coefficients as illustrated in Figures 7a, b, c and d.



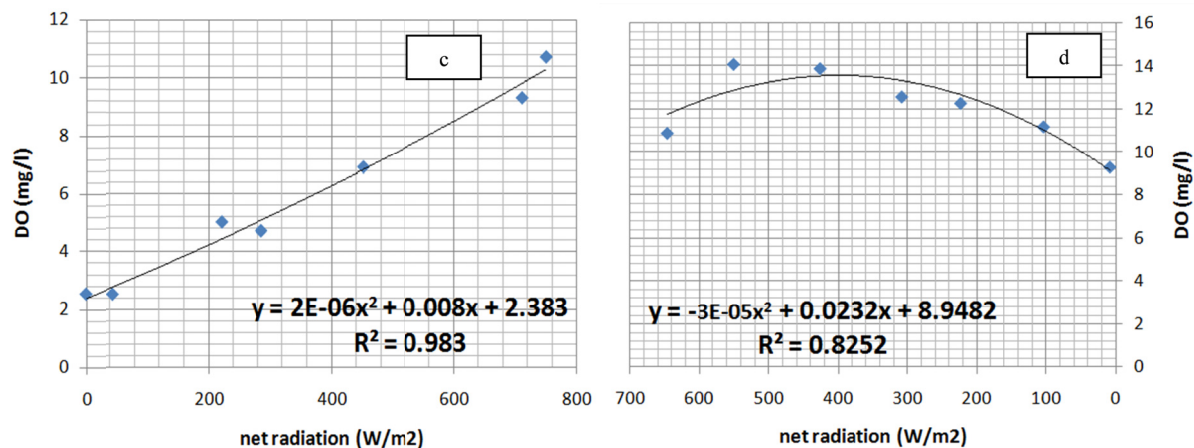


Figure 7. Graphical illustration for the relationship between solar radiation and DO in wastewater treatment ponds of the Royal LERD project site; (a) sedimentation pond 1 in the morning, (b) sedimentation pond 1 at noon, (c) oxidation pond 3 in the morning and (d) oxidation pond 3 at noon

4.7 Quantity of Hydrogen Peroxide in Wastewater Treatment System

The measurement of H<sub>2</sub>O<sub>2</sub> in sedimentation pond 1 was found out 0.34 µg/L in the morning at 10:00 a.m. and met the maximum value of 1.18 µg/L at 01:00 pm (producing rate 0.28 µg/L/hr). After that, the quantity of H<sub>2</sub>O<sub>2</sub> was gradually decreased from 0.76 µg/L at 02:00 p.m. to 0.08 µg/L at 05:00 p.m. (decreasing rate 0.27 µg/L/hr). For oxidation pond 3, the amount of H<sub>2</sub>O<sub>2</sub> was found 2.04 µg/L at 06:00 a.m. and climbing up to the maximum increasing of 2.89 µg/L at 04:00 p.m. (producing rate 0.11 µg/L/hr), then it decreased down to 2.38 µg/L at 07:00 p.m. (decreasing rate 0.17 µg/L/hr) as shown in Table 4.

Table 4. Quantity of H<sub>2</sub>O<sub>2</sub> in Phetchaburi municipal wastewater treatment system of sedimentation pond 1 and oxidation pond 3 at the Royal LERD project site

Time (hr.)	Net radiation (W/m <sup>2</sup> )	H <sub>2</sub> O <sub>2</sub> (µg/L)	
		Sedimentation pond 1	Oxidation pond 3
06.00	0	0.0	2.04
07.00	45	0.0	1.62
08.00	222	0.0	1.36
09.00	286	0.0	2.04
10.00	452	0.34	2.30
11.00	711	0.51	2.46
12.00	750	0.68	2.46
13.00	646	1.18	1.87
14.00	550	0.76	2.72
15.00	426	0.51	2.64
16.00	308	0.34	2.89
17.00	223	0.08	2.64
18.00	103	0.0	2.38
19.00	8	0.0	2.38

From Table 4, H<sub>2</sub>O<sub>2</sub> in sedimentation pond 1 and oxidation pond 3 were varied directly to total solar energy (William & Zika, 1983) and maximizing in the afternoon period, that the same trend as southern California which found maximum accumulative H<sub>2</sub>O<sub>2</sub> in the sea in the afternoon (Catherine et al., 2010) according that solar energy encouraging molecule of DO and water (H<sub>2</sub>O) being separated into free radical, i.e., OH\*. After that, the OH\* will

take an action to gain the product of  $H_2O_2$  (Gerringa et al., 2004; Steven et al., 2010) which varied directly to increase and decrease of solar radiation but the decreasing of  $H_2O_2$  in sedimentation pond 1 was not similar to oxidation pond 3. The decreasing in sedimentation pond 1 of  $H_2O_2$  could be attached at 0.00  $\mu\text{g/L}$  while oxidation pond 3 was still found with continuous delectability because of the rapid decreasing of DO in sedimentation pond 1 during the afternoon period. Since, the molecules of oxygen was affected to the decrease of primary object of  $H_2O_2$  occurring, which could not be found out  $H_2O_2$  in sedimentation pond 1 after 06:00 p.m.

For clearly understanding, the polynomial correlation was studied on the relationship between solar energy and  $H_2O_2$  and found out the correlation coefficient in sedimentation pond 1 0.944 and 0.986 in the morning and afternoon, respectively (Figure 8a and b). For oxidation pond 3, the correlation coefficients of  $H_2O_2$  were detected as 0.606 and 0.700 in the morning and in the afternoon, respectively (Figures 8c and d).

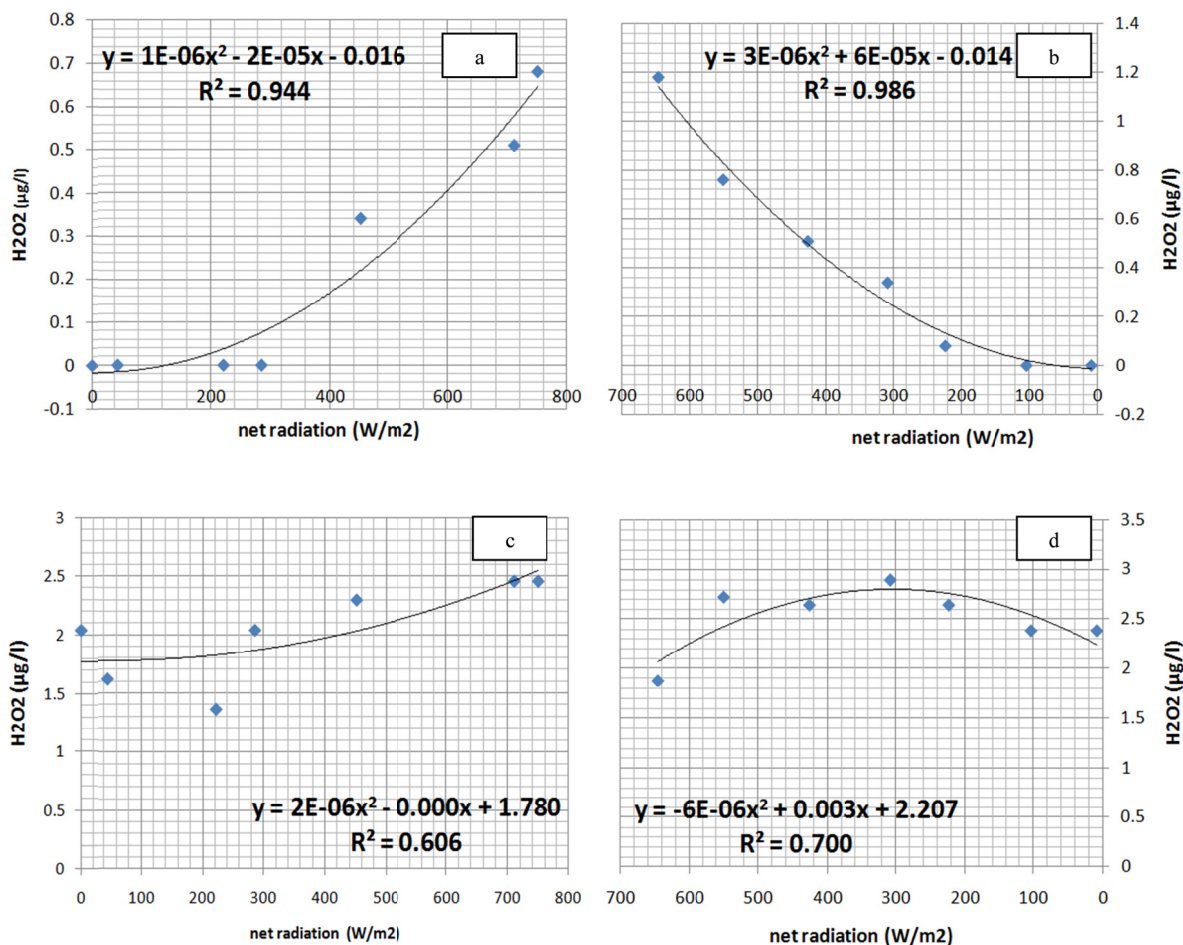


Figure 8. Graphical analysis of the relationship between solar radiation and  $H_2O_2$  in Phetchaburi municipal wastewater treatment system in sedimentation pond 1 and oxidation pond 3 at the Royal LERD project site; (a) sedimentation pond 1 in the morning, (b) sedimentation pond 1 at noon, (c) oxidation pond 3 in the morning and (d) oxidation pond 3 at noon

## 5. Conclusion

Due to the previous studies of community wastewater treatment under H.M.The King's initiative nature by nature process on Laem Phak Bia environmental research and development project at Laem Phak Bia sub district, Ban Laem district, Phetchaburi province in Thailand have been implemented since the year of 1990 up to the present time and found the drastic decreasing of total coliform and fecal coliform after draining out of wastewater from the tip of 18.5 km. HPDE pipe to sedimentation pond 1 through another four consecutive oxidation ponds (ponds 2, 3, 4 and 5), especially after overflowing weir crest of oxidation pond 3 that found very less down to zero MPN/ml. In depth study on the effect of solar energy on DO and  $H_2O_2$  in wastewater treatment ponds found that the solar radiation as measured at the Royal LERD project site resulted 0-750 Watts/m<sup>2</sup>. This amount of solar energy can

make the separation of oxygen in wastewater to encourage the H<sub>2</sub>O<sub>2</sub>. Besides, the solar energy was still shown the relation to DO and H<sub>2</sub>O<sub>2</sub> in sedimentation pond 1 rather than the oxidation pond 3, due to the lower quantity of dissolved organic and inorganic matters in oxidation pond 3 than sedimentation pond 1. It was affected to aerobic bacterial organic digestion processes not employing less oxygen as electron acceptor. In other words, the oxygen as occurred from phytoplankton photosynthesis could not be employed for processing of organic digestion and respiration in very small amount on night time, and let it be accumulated oxygen in water. Therefore, it makes sure that the amount of DO and H<sub>2</sub>O<sub>2</sub> in oxidation pond 3 did not vary directly to total solar energy.

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