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Evaluation of Dissolved Oxygen Stratification in an Oxidation Pond for Community Wastewater Treatment through King's Royally Initiated "Nature by Nature" Process

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Abstract

Oxygen in the air transfer to wastewater in oxidation ponds through many ways and the vertical water circulation is the one of them which are needed thermal stratification of water for process flow. Therefore this research designed to set three sampling sites (points A, B and C) at midpoint transect of oxidation pond, they were perpendicular to the influent current of wastewater input from inlet for measuring indicators that have relation with vertical water circulation i.e. temperature, DO, pH, TDS, EC and salinity in each depth. By using indicators together with statistical analysis, the result found the middle sampling site (point B) as the most appropriate to be more intensively monitored. The point B was used to collect and to analyze the samples for evaluated dissolved oxygen (DO) stratification of wastewater in an oxidation pond and its showed 3 zone of DO stratification that are the top zone at surface to 60 cm depth as almost DO at here, the middle zone at 60-150 cm depth as DO decrease slowly but belong to balance, and the bottom zone at more 150 cm depth as DO dwindle to get zero and also identified as anaerobe zone.

Keywords: Dissolved oxygen and temperature stratification; Oxidation pond; Community wastewater treatment

1. Introduction

Water is important among environmental resources in giving helps to the human lives in terms of culture and arts, folkway, livelihood, lifestyle and well being, especially transportation, economic crop growing, aquaculture, waterworks, recreation, sport and etc., past three decades learnt that mismanagement of water caused water problems in the whole kingdom of Thailand. Consequently, the government has put an effort to solve the water problems but it seems blur because of too often of changing politically in government, and rapidly climate change together with global change not only in Thailand but also around the world.

The government has tried to solve both water quantity and quality issues, to manage wastewater problems from rock-mineral soil based, mining operation, community, industry, agriculture, constructing road or highway, and natural disasters. Among those activities, water quality problem is dominated from communities rather than anything else in Thailand due to more dense population along the riverbanks as mainly localization, tourism promotion (approximately 66 million in the year of 2018), uncountable food factories (frozen chicken, pork, beef, and aquatic animal), including catering services, fresh and canned vegetables, local canned fruits, flowers and dry food. In doing so, the produced wastewater cannot be avoided draining into water sources that found their distribution around the country, generating not only damaging physical, chemical and biological water quality but also death of aquatic plants and animals. Nowadays, the dwellers in Thailand has been confronted with wide-spread wastewater impacts, especially lowland areas. (Faerge *et al* ., 2001; WHO, 2006; Sperling, 2007; Chunkao *et al.,* 2012)

The government together with lawful privatization agencies have been annually disbursed quite a big budget, but community wastewater boundary still increasing, particularly the dense populated cities such as Bangkok, Petchaburi, Nontaburi, and etc. The results cannot be competed with expenditure that may utilize the inappropriate technology and lack of experience of community wastewater managers. This is the reason why King Bhumibol Adulyades Royally initiated the nature by nature process (NBN process) taking the Royal LEAD project site for solve community wastewater, and to expend to the other part of the country. However, the Royal Initiative NBN process in oxidation pond (depth = 2 m to 3 m, length = 3-5, width, and HRT 5-7 days) is mainly comprised of thermo-siphon, photosynthesis, and thermo-osmosis processes, but the first two processes seem to be dominated. (Gutterer *et al.,* 2009; Hassan, 2011; OTCP-staff, 2011; Grosse, 2012; Al-Hashimi, 2013; Ishfag, 2016) In principle, the thermo-siphon process (fluid mechanism that is vertical circulation by thermal stratification) is generated during evaporation process from surface wastewater by absorbing heat (584 cal/gm heat of vaporization) on the surface wastewater that makes surface water cool and heavier than wastewater body. This cool surface wastewater is ready to sink down to the bottom of oxidation pond and carrying dissolved oxygen (DO) too. Naturally, community wastewater is composed of green algae (especially phytoplankton) beside microorganisms that induces to generate DO through photosynthesis but it happens only the depth of visible light penetration at about 30-cm depth. In other words, the oxidation pond that contains community wastewater can be received DO by thermo-siphon and photosynthesis processes in which it plays role in providing to microorganisms for activating 'bacterial organic digestion process' to convert organic matters to become inorganic materials. It is obvious that DO product from photosynthesis process is available only at about 30-cm depth but it is hard to happen below this level. So, the thermo-siphon process has to assist in bringing DO with cool air by sinking from the surface to the deeper level of 30-cm depth towards the bottom. (Arneth and Stichlmair 2001; Gehlin, 2003; Chindah *et al.,* 2007; Liu *et al.,* 2012; Liu *et al.,* 2014; Kumar and Arakeri, 2015)

Normally, an oxidation pond is located in the open air with the size of rectangular shape of length equivalent to 3 to 5 times of width; and filling wastewater at the level of 4 in 5 of water depth.(2-3 m) which is the appropriate depth. Thermo-siphon process originates from surface wastewater evaporation which becomes cold and heavier due to increase density together with high concentration of dissolved oxygen (DO). Then after, the surface wastewater mass was sink to the bottom as stated above. It is suggested that lowered DO concentrations are caused by bacterial metabolism. (Craggs *et al.,* 2003; Liu, 2007; Mara *et al.,* 2007; Maiga *et al.,* 2009; Metcalf and Eddy, 2013; Jimenez *et al.,* 2014; Menezes *et al.,* 2015)

Accordingly, the temperature stratification plays a significant role in bring along DO from the surface to the bottom. The sinking depth is depended on the heat absorption of evaporation process on surface water, concentration of organic matter, effective inhibitors, and heat liberation during bacterial organic digestion process. Purposively, this study is really needed to allocate the minimum numbers of sampling point on the surface in order to use for sinking DO through thermo-siphon process as the basic background of King Bhumibol's Royally initiative nature by nature process.

2. Materials and Methods

2.1 Area Description

There are 5-consecutive oxidation ponds for municipal wastewater treatment located at "The King's Royally Initiated Laem Phak Bia Environmental Research and Development (Royal LERD) Project Site", Laem Phak Bia sub-district, Ban Laem district, Phetchaburi province as shown in Figure 1.

Oxidation pond no.2 among 5 ponds on the surface area was selected to study on the promising sampling point in relation to evaluating vertically temperature stratification sinking cold water which may carry oxygen from above to lower water levels. Three sampling sites were settled on the pond (points A, B and C) which was supposed to perpendicular with the influent current. The first sampling site (point B) was demarcated on the center while the other two sites (points A and C) took over between the center and pond edges on the right and the left. All three points were demarcated 8 levels on and below surface at depths of surface (t1), and t2 to t8 at 15, 30, 60, 90, 120, 150 and 180 cm respectively, and 3 points upper surface ta, tb and at the height of 20, 40 and 60 cm, respectively, respectively as sampling points of temperature, DO due to cold water sinking, and water quality indicators (pH, TDS, EC, and salinity) as shown in Figure 2. Also, the small white roofs (with the size of 55-cm width, 55-cm length, and 80-cm height) were built above water surface about 20 cm for installing thermometer by installing data locket recorder (Figure 2). The experiment was utilized the climatic station (it was automatically operated and recorded in data loggers all the time) as located inside the Royal LERD project site for supporting data on ambient air temperature, relative humidity, wind speed and direction, evaporation, rainfall, and solar radiation (Figure 3).

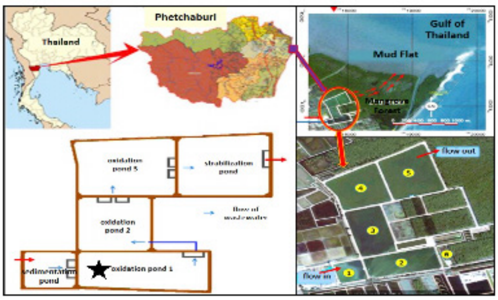

Figure 1. Royal LERD project site and 5-consecutive oxidation ponds for municipal wastewater treatment as located 18.5 km from 40,000 population Phetchaburi city (Oxidation pond no.2)

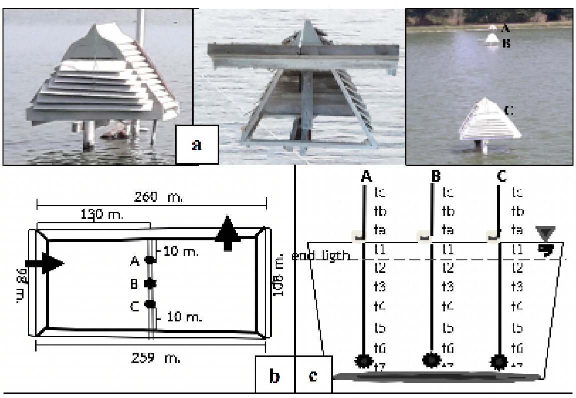

Figure 2. Localization of three sampling sites (perpendicular with influent flow) together with demarcating 8-level depths form surface water and another 3-level points above water surface for measuring water quality

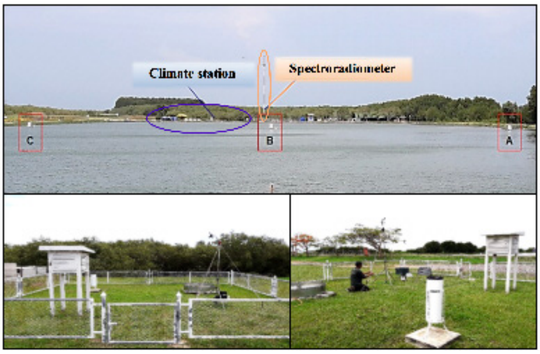

Figure 3. Royal LERD climate station by installing the instruments for measuring solar radiation, rainfall, ambient air temperature, wind speed and direction, relative humidity, and evaporation.

2.2 Sample Collection and Data Analysis

The sampling data of water quality indicators (DO, pH, TDS, EC and salinity) were measured on standard methods for the examination of water and temperature in each depth of wastewater was recorded by automatically instruments all the time. The meteorological indicators were monitored using weather station set and solar radiation was monitored by spectroradiometer at Royal LEAD project site (APHA *et al.,* 2005).

The field data was analyzed graphically to determine the thermal and DO stratification of community wastewater in oxidation pond with a two-way ANOVA and statistical significance at 0.05 (α = 0.05). (Tadesse *et al.,* 2004; Perello *et al.,* 2017).

3. Results and Discussion

The ambient air temperature as measured on 3-level heights were obtained at *20, *40 and *60 cm (*above from surface water) which was gradual increased from levels *60 to *20 cm (is the nearest evaporating wastewater surface). While the wastewater temperature at 0 (surface), 15, 30, 60, 120, 150 and 180 cm depths were found drastic decreased from surface to the bottom as shown in Table 1 and Figure 4 (average all the time).

The statistical variation analysis by two-way ANOVA in statistical α = 0.05 found no significance among wastewater in each depth of points A, B and C as shown p-value of surface (0 cm) was 0.056, and water depth at 15, 30, 60, 90, 120, 150 and 180 cm were 0.278, 0.597, 0.382, 0.389, 0.461, 0.363 and 0.355 respectively; and also the ambient air temperature at *20, *40 and *60 (height above water surface) as shown no significance among levels in p-value was 0.973. The results can be interpreted that it could used 1-leval at above water surface for measure temperature of ambient air and select 1-point (from A, B and C) for measure temperature in each depth of water. Instead of decreasing temperature while cold water sinking, the heat as obtained from bacterial organic digestion process was liberated to maintain the temperature. (Badrot-Nico *et al.,* 2009; Kumar and Arakeri, 2015)

The results of some water quality indicators were not shown in any changes from statistical analysis which were pH, TDS, EC and salinity together with those data analysis and the average of the each point was also calculated as shown in Table 2 and Figure 5. There were no significantly difference between measuring level measurement of pH, and salinity, while highly difference between depths of measuring DO due to cold wastewater sinking, even though there is no differences of wastewater-depth temperature. Actually, the cold wastewater was sank until the temperature of water no difference. So far, either one of points A, B, and C can be selected for sinking cold water (plus DO) which was expected to be the appropriate sampling site (point). Finally, the research team has selected the middle site (point B) because it was very close to the middle of influent flow from inlet rather than the other two points. Also, it was located in the middle of pond which could be the better representative sampling point of wastewater quality (Kochany and Lipczynska-Kochany 2009; Geng and Duan 2010).

The DO profile of pond was significantly decreased from the surface to the bottom as shown in Table 3 and Figure 6. In principles, the colder water was heavier weight and sinking by gravitational forces under the thermo-siphon process due to more water molecules in the same volume belonging to warmer water. It was suggested that DO concentration was reduced by microbial metabolism (Hull *et al.,* 2008; Lee and Saylor 2010).

In the results shown average DO at the bottom of the pond (the depth of pond no.2 is 2.10 m.) was 1.07 mg/l while there wanted to know where DO was zero, therefore it was extended the depth of pond to 3 m (Figure. 6). The aforesaid statement indicated that the effective depth of oxidation pond can be more or less 3 m which should be taken in using for community wastewater treatment (Berkun, 2005; Hull *et al.,* 2008; Chatelain and Guizien, 2009; Sah *et al.,* 2011, Ivanov *et al.*, 2012; Menezes *et al.,* 2015).

Due to the depth of oxidation pond 180 m plus another 120 cm for attaching zero-DO depth, the DO stratification zones could be divided into 3 depth zones, namely top zone (at depth of 0-60 cm), middle zone (at depth of 60-150 cm) and bottom zone (at depth of 150-300 cm). The top zone can be characterized as the ranging depth of high concentration of DO together with narrow changes in DO decreasing and decreasing because of cooler wastewater by thermo-siphon process plus high product of DO from photosynthesis process. While middle depth zone is the ranging depth of highest rate of DO consumption for bacterial organic digestion process that makes imbalance between DO input and DO consumption. The last depth zone is called as bottom zone which is very low rate of DO consumption because of very low amount of DO availability, mostly facultative zone down to anaerobic zone. Actually, the above statement is really needed to insist that the appropriate depth of oxidation pond should be deep between 150-300 cm. The first oxidation pond should be about more or less 300 cm, and gradually decreasing depth and directly relation to the concentration of organic wastes. From experimental experiences, the concentration of community wastewater as measured by BOD should not be greater than 200 mg/L together with 3-consecutive oxidation ponds (Craggs *et al.,* 2003; Berkun, 2005; Kochany and Lipczynska-Kochany, 2009; Maiga *et al.,* 2009; Lee *et al.,* 2013; Metcalf and Eddy, 2013; Bouffard *et al.,* 2014, Chaturvedi *et al.,* 2014, Menezes *et al.,* 2015; Bai *et al.,* 2016).

Table 1. Temperature of ambient air at 3-levels, each wastewater depth on 3 points (A, B and C) and average in the pond

Temperature on 3 Points in the pond											
Point	**Depth (cm)**										
	***60**	***40**	***20**	**0**	**15**	**30**	**60**	**90**	**120**	**150**	**180**
A	29.43	29.45	29.5	32.01	31.82	31.66	31.32	31.19	30.99	30.85	30.78
B	29.34	29.39	29.48	31.79	31.78	31.62	31.3	31.08	30.89	30.76	30.66
C	29.35	29.38	29.49	31.67	31.63	31.57	31.43	31.21	30.88	30.73	30.65
Average	29.37	29.41	29.49	31.82	31.74	31.62	31.35	31.16	30.92	30.78	30.7

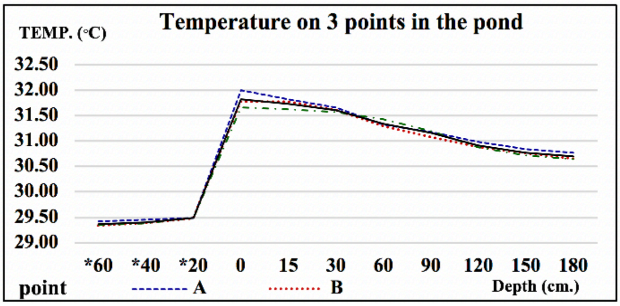

Figure 4. Profile of temperature of 3 points and average in ambient air height *60, *40 and *20 cm, on surface (0 cm), and at wastewater depth 15, 0, 60, 90, 120, 150 and 180 cm

Table 2. Distribution of wastewater quality indicators at depth of 0 to 180 cm (average from 3 points: A, B and C)

Indicators	Depth (cm)							
	0	15	30	60	90	120	150	180
pH	8.23	8.31	8.29	8.22	8.06	7.96	7.87	7.84
TDS	689.34	689.63	690.38	693.53	698.11	700.71	702.1	703.14
EC	1043.33	1044.1	1045.83	1049.43	1056.63	1060.46	1062.32	1064.08
salinity	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

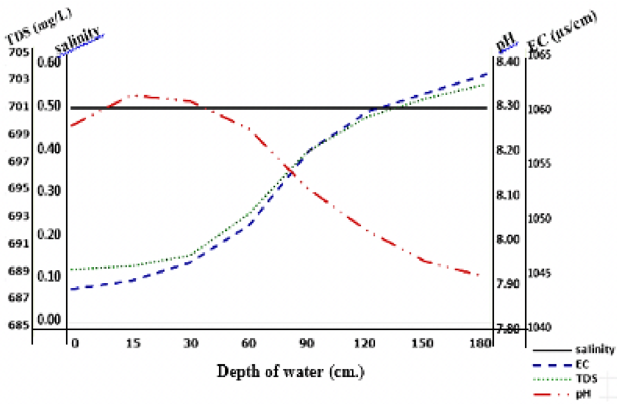

Figure 5. Profile of wastewater quality indicators of pond on surface (0-cm), and depth of wastewater: 15, 30, 60, 90, 120, 150 and 180 cm (average from 3 points: A, B and C)

Table 3. Dissolved oxygen sinking to wastewater depth of points A, B, C and average in oxidation pond

Point	Depth (cm)							
	0	15	30	60	90	120	150	180
A	8.04	7.77	6.99	5.72	3.74	2.44	1.62	0.48
B	6.66	6.54	5.89	4.96	3.52	2.55	1.80	1.26
C	8.12	8.13	7.95	7.45	4.75	2.87	2.06	1.48
Average	7.60	7.48	6.94	6.04	4.00	2.62	1.83	1.07

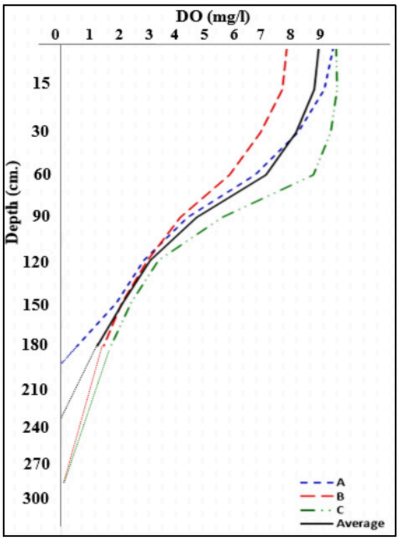

Figure 6. Profile of dissolved oxygen sinking to wastewater depth of points A, B, C and average in oxidation pond on surface (0-cm), depth at 15, 30, 60, 90, 120, 150 and 180 cm

4. Conclusion

The study on determining the effective stratification of sinking cold water as the indirect means for assessing the sinking DO for community wastewater treatment through the King's Royally initiative nature by nature process. Three points at 8-level depths were localized on the middle point of a half-length of oxidation pond no.2 together with installing at each depth of 0 (surface), 15, 30, 60, 90, 120, 150 and 180 cm. also thermometers for measuring ambient air temperature were installed at height of 20, 40, and 60 cm above water surface, including Royal LERD climatic station. The applicable indicators as used for research were included DO, temperature, TDS, EC, pH, and salinity by collecting the samples on June 2017. After analyzing the samples, the middle sampling site (point B) was selected as the most appropriate sampling point for measuring not only for this research but also for general application whenever the oxidation pond used for community wastewater treatment. Finally, the DO profile was found by dividing to top zone (0-60 cm) with balancing DO, middle zone (60-150 cm) with high rate of DO decreasing, and bottom zone (150/300 cm) with very less rate of DO decreasing.

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