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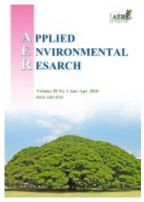

Enhancing High-concentrated Wastewater Quality on Evaporation Rate from Five-Consecutive Oxidation Ponds as Located in Phetchaburi, Southerly Thailand

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Abstract

This research aimed to examine the environmental factors determining the rates of evaporation, a natural phenomenon contributing to the treatment of wastewater of 5-consecutive oxidation ponds of the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project. Data collected from the 17th of April to 30th of May 2019 by US Class A Evaporation Pan revealed that the sedimentation pond (Pond 1) has the highest rate, 7.22 mm d^{-1}, the oxidation pond 1 (Pond 2), 5.70 mm d^{-1}, the oxidation pond 3 (Pond 4), 5.56 mm d^{-1}, the stabilization pond (Pond 5), mm d^{-1}, the reference pond at 5.07 mm d^{-1} and the oxidation pond 2 (Pond 3), 3.59 mm d^{-1}. Concluding the evaporation in domestic wastewater treatment plants is characterized by 1) heat generated from short and long wave radiation emitted by earth and the sun, 2) local wind profiles of the area affected the height differences of the roughness length, and 3) heat generated by the respiration and digestion process of microbial activities and other grey body contaminants. Presenting the day and night variations made for the analysis, the day evaporation was significantly higher resulted by the net radiation were accountable. Wind profile generated from the measurement of speeds and directions at two different sites at 3 and 10 m has explained for the roughness length heights over each pond as lower roughness height have cause the increased in the rates of evaporation in Pond 4 and 5 however, these processes were also suppressed by high ionic bonding molecules effected suggested by the high TDS and EC values. The vertical temperature profile has conveyed the movement in the heat flux that dominated an upward flux movement in Pond 1. This is the exothermic reaction from the digestion process have suggested that extra heat has been added.

Keywords: Wastewater; Wind velocity; Oxidation ponds; Evaporation; Nature by nature process

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Introduction

Community wastewater issues have been gradually degraded since the year 1970 and turned to be serious catastrophes a few years later in the whole Kingdom of Thailand [1]. Having spent a large portion of the annual budget to try to eliminate and manage community wastewater it was made clear by certain areas of the country that were dominated from dense population along the riverbanks [2], the discharge of domestic wastewater from daily activities such as cooking, washing and bathing has cause dramatic effects towards the local environment [3]. Furthermore, extensive deforestation has lead to further contamination of water in streams through nutrient pollution [4]. In resolving such problems, H.M. King Bhumibol has realized the problems of stream pollution around the country and initiated the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Chaipattana Foundation (LERD) emphasizing on the nature by nature process using oxidation ponds treating approximately 5,000 cubic meter of wastewater per day.

In efficiently treating the wastewater, the application of the evaporation process as a natural phenomenon to support wastewater treatment system. As a driver for the underwater fluid circulation driven by the thermosiphon effect, the physical process in which the movement of water in a vertical profile depended on the differences in the temperature gradient of the water column inside the pond. [5]. The uses of thermosiphon process are dominated by the process used in the transfer of oxygen throughout the vertical profile of the oxidation pond [6]. Knowing that the production of the thermosiphon effect in an open surface area requires evaporation. The rate of evaporation in oxidation ponds is known for the generation, absorption and transfer of energy using the evaporation process through the latent heat of evaporation [7]. The rate of evaporation can be assessed using the "Class-A evaporation pan" [8]. The thermal energy needed in the process of evaporation of 1 g of water amounts to 583 calories at 25°C [9] transferring it into the latent heat energy in the evaporation process.

Evaporation from the surface is proportional to the difference between actual water vapor pressure and the saturation water vapor pressure [10]. Factors causing different rates of evaporation which are meteorological index surrounding the water body: sun irradiation, air temperature, air humidity and wind speeds [11]. While to also noting the research site is an open area located next to the gulf of Thailand, the influencing factors from the sea would also bring about the differences in the rate of evaporation. This study aims to provide an additional insight into these mentioned elements influencing the rates of evaporation that is related to the water quality and its physical, chemical and biological contaminants together with the anaerobic and aerobic digestion factors which in consequence have an impact on the thermosiphon process, a key for improving the effectiveness of current oxidation ponds and their future design [12].

Materials and methods

1) Study site

This research was carried out at the LERD, Phetchaburi Province, Thailand utilizing the nature-by-nature processes adapting oxidation pond treatment system for treating of wastewater from the Phetchaburi municipality wastewater system. The wastewater is transferred to the collection pond (Klongyang collection ponds) through an 18 km long HDPE pipeline with the diameter of 400 mm into the treatment ponds (Figure 1) The LERD Project established by King Rama the 9th consists of 4 different systems of oxidation ponds, plants filtration, constructed wetland and mangrove forest using simple and inexpensive technologies [13]. The treatment in the oxidation pond is achieved by the process of naturally occurring aerobic microbes digest organic materials in the domestic wastewater transforming them into minerals and inorganic substances.

2) Class A evaporation pan and installation of the adapted float evaporation pans

The measurement of the evaporation rates was conducted using the US Weather Bureau Class-A pan; diameter of 1.207 m and a depth of 0.25 m. The pan is a galvanized steel that has been adapted to base placed on a wooden structure 0.15 m above ground. The water level in the plate is set for 0.05 m [15]. In creating a night and day variation, the evaporation data was recorded into a 12-h period (6:00 and 18:00), which represented the day and night variation base on the shortwave radiation emitted by the sun [16]. The data were taken from April 17th to May 30th 2019 (N=84) for each of the ponds and a reference site. The measurement of water evaporated during each period was gauged with the steaming cup located in the center of the evaporation tray. This was done by using the hook gauge to read of the water level at the starting point of the 12-h period and then taken again at the next 12 h. The changes in the water level will be the amount of water that has evaporated, however, in case of rain these measurements have to be corrected using the amount of rain (in mm) from the 8-inch rain gauge at the reference site at the climate station [17]. The adaptation of the pan for measuring the actual wastewater evaporation directly from each treatment pond (Figure 2). The evaporation pans were mounted firmly in place and protected from external influences such as waves, or wind. The pan was held in place at the center of the treatment pond. The installation of the evaporation pan follows the guidelines of set following Part III of the Manual on the Global Observing System, the Guide to Meteorological Instruments and Methods of Observation [13, 18].

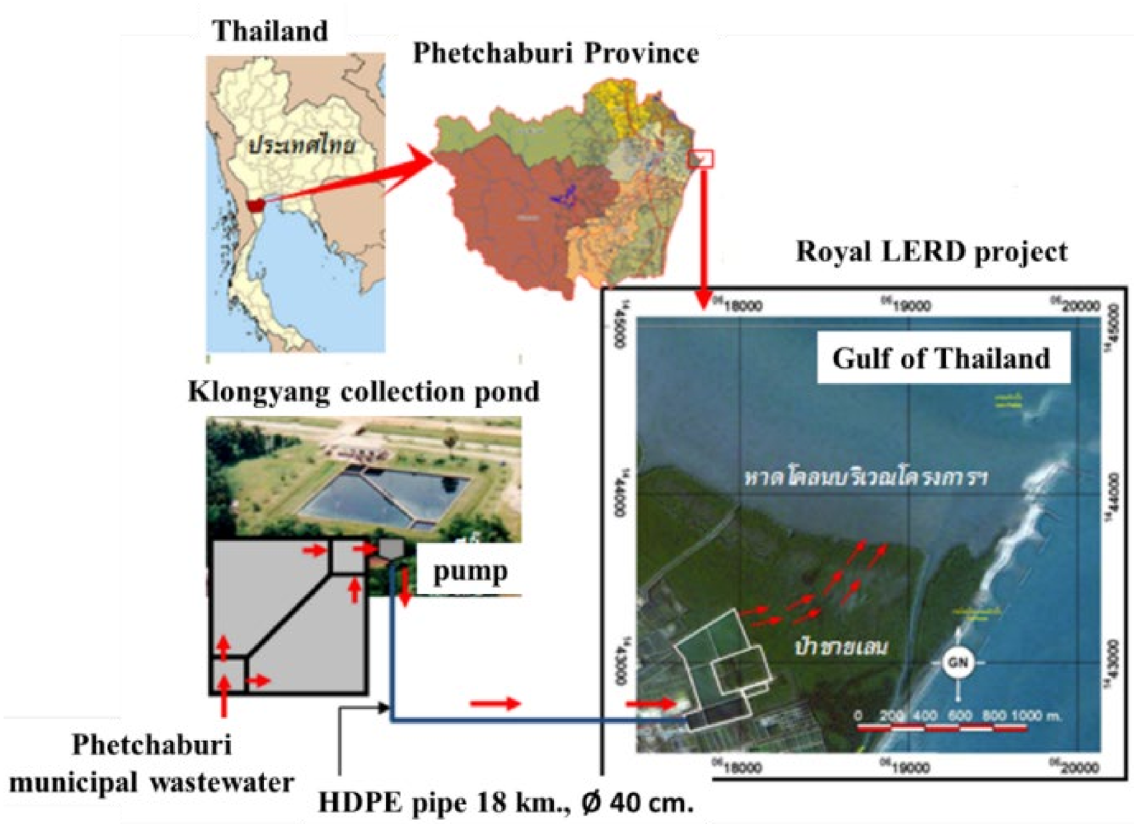

Figure 1 The Location of Phetchaburi and LERD project site.
Source: Penman [10]

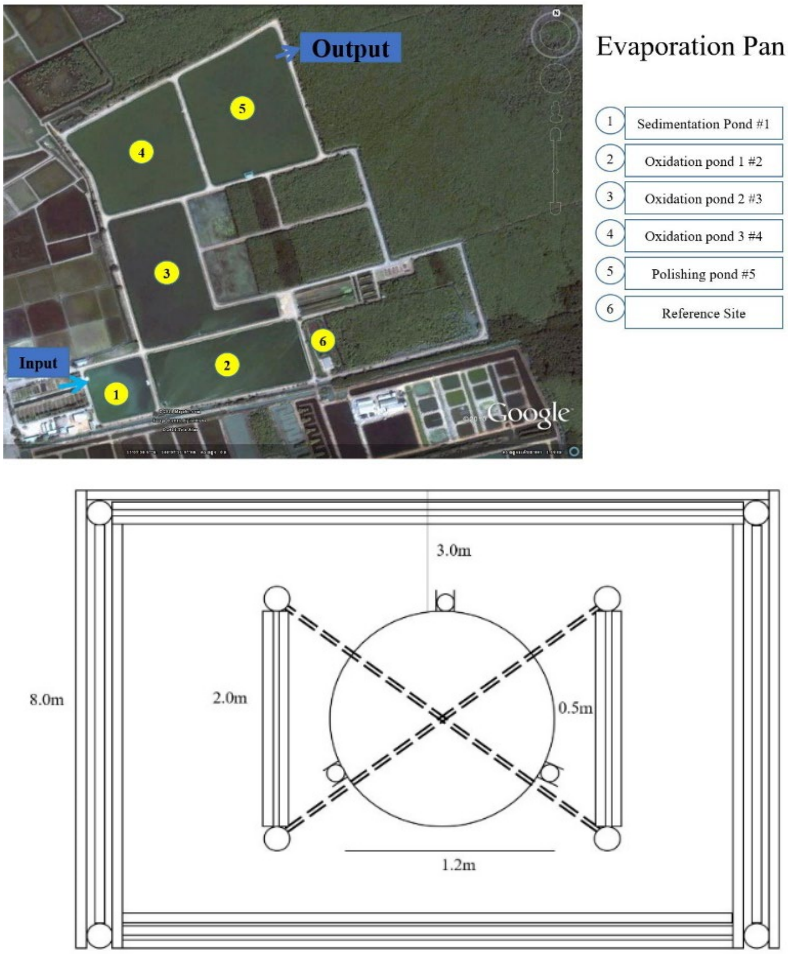

Figure 2 Setup of the Class-A evaporation pan over the LERD project oxidation pond.

3) Evaporation measurement

Measurements were conducted daily from April 17th until May 30th, 2019 (N=84), where Evaporation data collection was taken from each individual pond 1, 2, 3, 4, 5 and the reference pond, respectively. The measurement of water evaporated during each period was gauged with the steaming cup located in the center of the evaporation tray. This was done by using the hook gauge to read of the water level at the starting point of the 12-h period and then taken again at the next 12 h. The changes in the water level will be the amount of water that has evaporated, however, in case of rain these measurements have to be corrected using the amount of rain (in mm) from the 8-inch rain gauge at the reference site at the climate station [17].

4) Wind speed and direction of anemometer measurement

The wind speed and direction is measured hourly by the anemometer. The anemometer is placed at the surface of each pond, while the other two site in the study area is at 3 and 10 m where this is in order to measure the site surface wind speeds, use in calculation of the rates of evaporation. With the first spot in between Pond 1 and 2 while the second spot was in between Pond 4 and 5 (Figure 3). At the reference site was a 3m at the LERD climate station.

While also having the wind profile being generated from the wind profile, it was that the wind movement beforehand the estimated roughness height under this particular terrain is predicted to 30 cm as 5 wind speeds/direction anemometer was place besides the evaporation pans of each pond (Figure 4).

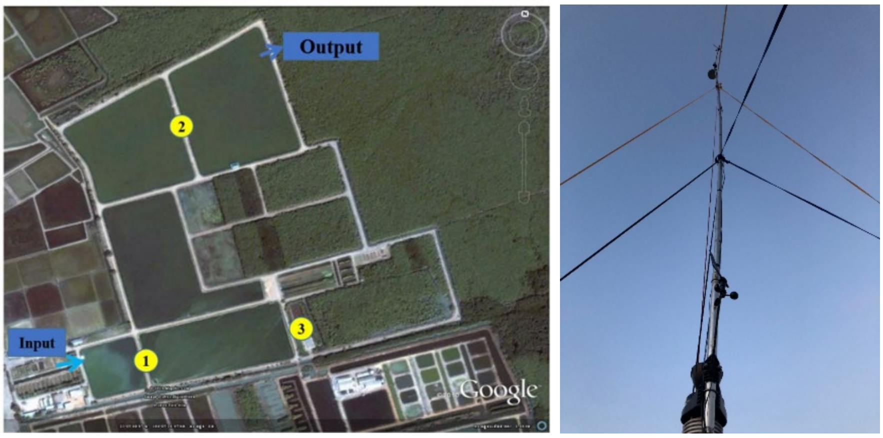

Figure 3 Setup of the anemometer the LERD project's climate station.

Figure 4 Setup of the Class-A evaporation pan over the LERD project oxidation pond.

5) Analysis of quality relationships and the evaporation rate in the pond

In relation to the physical, chemical and biological factors of water. That can be suggested from the generation of heat through the microbial activities and radiative properties on the rates of evaporation. The process in taking the water samples, the sampling methods are specified by the Pollution Control Department (PCD) for the Standard Method for Water and Wastewater [19], where the samples were collected at the middle of each treatment pond once a week during midday (12:00), for 7 weeks to represent the overall water quality. The analyzed parameters include 11 parameters of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), Electro conductivity (EC), salinity, suspended solids, pH, surfactant, turbidity, color and transparency to determine the impact of each parameter to affect the rate of evaporation [20].

6) Ground and Water Temperature

Together with the measurement of the hourly ambient temperature of the air, the hourly water temperature was also taken into consideration in the rates of evaporation and the heat flux movement inside the pond. To measure the water temperature at different depths, thermometers probes were placed with the separation of the ratio into 0.3 0.6 and 0.8 of the actual depths of the pond with the actual depth. While at the reference site, it was that the probes were placed at 0.30 m, 0.60 m and 0.80 m into the soil sample.

Results and discussion

1) Analysis of evaporation in Class-A evaporation pans

The measurement of the evaporation rates was taken place in the 5 different oxidation ponds of the LERD project and a reference site, which is a climate station. The total duration of the data collection process was a 42-d period in summer as this is the representative of Thailand's hot and dry season, from the 17th April to the 30th May 2019 in total of 42 d (N=84). The results of these rates of evaporation revealed that the sedimentation pond (Pond 1) has the highest rate of evaporation, at 7.22 ± 2.27 mm d^{-1}, the oxidation pond (Pond 2) at 5.70 ± 2.07 mm d^{-1}, the oxidation pond (Pond 4) at 5.56 ± 1.82 mm d^{-1}, the stabilization pond (Pond 5) at 5.27 ± 2.03 mm d^{-1}, the reference pond at 5.07 ± 1.83 mm d^{-1} and the Oxidation Pond (Pond 3) at 3.59 ± 1.57 mm d^{-1}.

The evaporation rates of each pond shown in Table 1 shows the evaporation data was separated into 12-h period during the daytime and nighttime was placed into the Duncan statistical analysis of statistical differences of p-values < 0.05.

In generalization, the evaporation rates found that during the day time was the highest rate was at Pond 1 while the rates of Ponds 2, 4, 5 and the reference pond were relatively lower. Pond 3, however, was the lowest as this also followed with the trends of the 24 hours' evaporation rates. The nighttime, likewise, posed a different generalization to the rates of evaporation over the pond as this has been clarified and grouped that Ponds 1 and 2 were still the highest with, ponds 4 and 5 and the reference pond and pond 3 showing the lowest rates of evaporation.

The results Duncan tests allowed for a comparison of evaporation rates with each other. With their values represent of the direct effect of the primary cause of evaporation, the present of sun light (solar irradiance). Where to evaporate water, energy is needed to break the hydrogen bonds between water molecules. The conversion of these energy is transformed form solar radiation or sensible heat from the air, water and soil [21] where from the significance differences of the day and night period, the evaporation rates is greatly impacted by total net radiation [22]. From the location of the experiment, the amount of solar radiation received was constant. With higher overall rates of evaporation happening during the sunlight hours, the total net radiation ranged from 300 to 850 watts per square meter. The rate of evaporation is then at most of all affected by this solar impact [23]. The experiment from Hammond et al. [24] it is suggested that the higher rates of evaporation were happening during the day with the explanation of the latent heat, stated that it is the energy that is absorbed and released in the generation of phases change as in this case would be in the form of liquid to gas stage (evaporation) [25].

2) Wind speeds and direction

Depicted from the evaporation rate differences cannot be explained by the solar radiation where it is regarded to be constant throughout the study area, other environmental conditions including wind speed and direction, water quality, ambient temperature and humidity were among the suggested variable that cause the differences over the different pond.

Table 1 Statistical analysis of day and night variation of the wastewater treatment ponds

	Pond 1	**Pond 2**	**Pond 3**	**Pond 4**	**Pond 5**	**Reference**
Average day	4.50^{a}	3.26^{b}	2.45^{c}	3.38^{b}	3.42^{b}	3.98^{b}
Average night	2.72^{c}	2.44^{c}	1.25^{e}	$2.18^{d,e}$	$1.84^{c,d}$	$1.09^{c,d}$

Table 2 Wind Speed measured at 3 and 10 m at the LERD project site

Wind speed (m s^{-1}) (Duncan[a,b])					
Anemometer location and height	**N**	**Subset for alpha = 0.05**			
		1	**2**	**3**	**4**
Pond 1 and 2 at 3m	98	2.09			
Pond 1 and 2 at 10 m	98		2.89		
Pond 4 and 5 at 3 m	98			3.26	
Pond 4 and 5 at 10 m	98				3.59

The wind profile generated in the area poses the direct impact towards of the roughness length (z_0). This was based on the structures around the wastewater treatment site as well as the wind direction that was influence by the land and sea breeze. Having known that the day time wind direction is impact by the sea breeze, the wind direction would have to pass through obstacles which are classified as the mangroves forests averaging in height of 6–10 m [26], conversely during the nighttime for the land breeze, the buildings of the LERD project (2 storey, 5 storey and 1 storey). By its relative location, the captivity zone [27] in which the roughness length of the creates a generated a higher standard deviation that would have prompted a lower evaporation rates [28]. This would imply that the treatment ponds (1, 2 and 3) that were located close the buildings and the mangroves, would be greatly influence. This assumption was then seen with the calculated z_0 in Pond 1 (sedimentation pond) and Pond 2 having the height of the roughness length to be 0.75 m, higher than that of Point 2 (Pond 4 and 5) 0.01 m as their location where an open flat area salt farm. From having such higher z_0 as a result from the increase of the frequency of the roughness distribution (land use) in the area would result in an increase in the evaporation rate [29], while also this was reflected with the lower wind speed across the area of Ponds 1, 2 and 3, the effects have led to a higher calculated at the estimated roughness length height of 0.30 m (Figure 5).

From Figure 5, the general trend that was observed that the rates of evaporation increased with wind speed. Ponds 4 and 5 been located in an open area have prompted a higher wind speed at 30 cm above the water surface. Ponds 1, 2 and 3 on the other hand shows the slightly lower wind speed as they were located in a location of lower wind speed. This effects were also co-relations with the actual rates of evaporation from the study of Penman [10] in which the experiment measures the rates of evaporation in which the factor that was derived from the promotion of wind speed effected the rates of evaporation were from 0.27 to 0.17. With is, the explanation for the higher evaporation in Pond 4 and 5 were dominated by the wind speed across the water surface. The wind effects, also influence the humidity with the area, where it is suggested that the increasing wind speed would cause the roughness over the water, evaporation is initially large, then decreases downwind because of the increasing humidity, therefore the increase in wind speed would allow for a more rapid replacement of the air over the water surface [10]. While wind factor is the explanation for evaporation over the open area, the high rates of evaporation at lower wind speeds area are needed to be explained with the quality of the water.

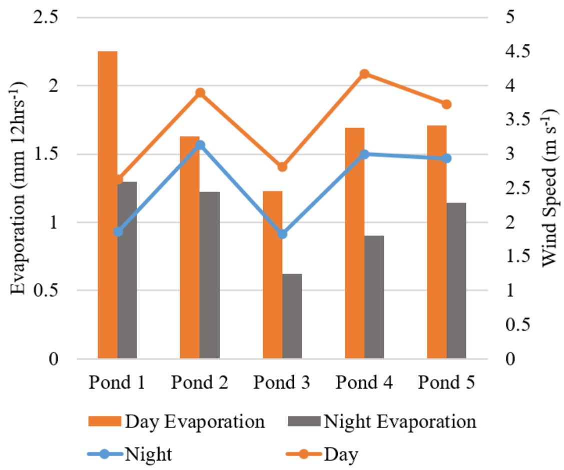

Figure 5 Wind speed at roughness length and rates of evaporation (day and night).

3) Evaporation data with wastewater quality

The linkage of the evaporation data with wastewater quality poses a different dynamic towards the rate of evaporation, as these factors are suggested for the difference in the water quality, with different biological, chemical, and physical conditions of the contaminants reacting that have altered the heat flux within the wastewater.

Determining the rates of evaporation in wastewater has been suggested for the heat that is generated through the physical, chemical, biological and the addition of contaminates together with the anaerobic and aerobic digestion factor which was seen in the temperature profiles and flux movements as base on the complexity of the water quality. Figure 6 and 7 shows the trends of the BOD, TDS and EC values of the wastewater as this is the representation the digestion processes within the ponds. [31] From Figure 6, the values representing the BOD suggested that higher BOD represent a greater anaerobic activity where this process as described are the natural nitrogen fixation the transformation of N_2 to reactive NH_3 is carried out by cyanobacteria is an exothermic reaction as the change in sensible heat (ΔH) is negative, implying that heat is given off during the reaction [32] as this would contribute towards the evaporation process. Where in evident of this can then be related to the heat reference the digestion and breakdown of organic matter as a composition of domestic wastewater is then considered an exothermic reactions generating in heat being released [20]. Shown in Figure 6 where the highest BOD found in Pond 1 emphasize the higher evaporation rate as these trends decrease from Pond 1 to Pond 3. However, from the BOD values in Ponds 4 and 5, the digestion process begins to slows down as the BOD are reduce to 16.1 ± 3.1 and 15.9 ± 2.6 mg L^{-1} respectively. It was also suggested that not only the chemical and biological activities are the only factors dealing with the addition of heat into the wastewater, the other suggestion is that the physical factors of the contaminants in the water behaves as a grey body, effecting with the variation within the energy and wavelength upon the incoming radiation as their properties are that of the emitter, reflectors, absorbers, transmitter, and refractor [33]. This then amplified the heat lag-time within the water body as it would allow for further evaporation to take place from the absorption of energy.

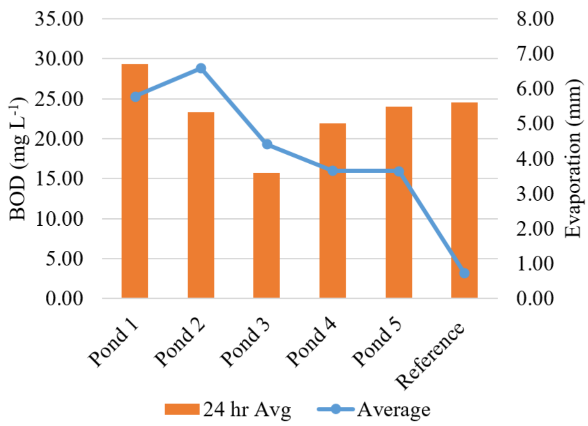

Figure 6 BOD and Evaporation

Depicting the increase in the rates of evaporation in Pond 4 and 5 can be explained in two parameters which includes TDS and EC, Pond 4 and 493.0 ± 24.5 mg L^{-1} and 736.4 ± 39.5 µS cm^{-1} and Pond 5 at and 560.8 ± 27.5 mg L^{-1} and 843.3 ± 51.2 5 µS cm^{-1}, respectively (Figure 7). From explanation of the breakdown of organic matter into inorganic materials by both aerobic and anaerobic processes causing an increase in ions in the wastewater recorded by TDS and EC values. [34] The influence on evaporation by the increase of ion coefficient of water, will cause an increase in the concentration of water as this would reduce the saturated vapor pressure of water as suggested that evaporation rates and partial pressure to retain the water molecules at the surface limiting the evaporation process as well as the ionic bonding [35]. On the other hand, the application with Ponds 1 and 2 with the higher evaporation have resulted from the lower ionic bonding between the molecules as water are attached by covalent bonding (Figure 7).

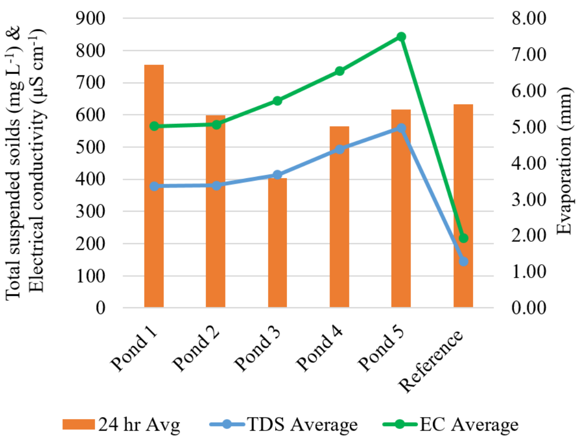

Figure 7 TDS & EC and Evaporation

From the highest evaporation in Pond 1, the heat flux was measured through the temperature profile was calculated using the heat to ground flux. The flux results in Pond 1 during the night time shows an upward flux movement as heat from the bottom moves to surface top of the pond. Suggested that when no present of short-wave radiation from the sun, the net radiation is dominated from the longwave radiation emitted by the earth, as the energy balance, measured within the area, suggested that as an average of 12 hours, the net long wave radiation of the out-going and incoming does not equal to one another as this differences are results in the storage heat that remains in the ground. In excess of the extra heat that is generated into the water body promoting the upward vector as also the excess heat generated by the microbial respiration activity during these hours would have also accounted from the upward flux movement.

Conclusion

Understanding the potential drivers for the evaporation within a wastewater treatment pond are achieved by comparing the relationship between the rates of evaporation from different wastewater ponds. The overall findings shown the general trends of water evaporation as effected by solar radiation and ambient conditions which includes temperature and humidity as the main direct impact of the night and day evaporative variations as solar shortwave irradiance amplifies the highest. Humidity and ambient air temperature creates different ambient air qualities to promote or limit the process of evaporation. Wind speed and direction in which the roughness length is determined suggested that the obstacles within the wind profiles created higher roughness height over the water surface generating a lower rate in evaporation. Water quality and ground heat flux within the treatment pond shows that having the highest domestic wastewater contaminants create the highest rates of evaporation as seen in oxidation pond 1 with 7.22 mm d^{-1} statically the highest. This is dominated by the night time heat flux or storage heat as well as anaerobic digestion in Pond 1, where the overall heat flux movement is negative (upwards from the bottom) by the digestion processes within the bottom layers of the ponds generating heat. The determination of this impacts on evaporation will help understand the better equipped the design of domestic wastewater treatment system efficacy and understand the thermosphoning phenomena achieved under the natural by nature processes.

Acknowledgements

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