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Effect of Solar Radiation on Cyanobacteria Bloom in Oxidation Ponds Community Wastewater Treatment at the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Phetchaburi, Thailand

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Abstract

Cyanobacteria blooming phenomenon was studied at the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project, Phetchaburi, Thailand. During cyanobacteria blooming, the most abundant species that found in oxidation pond was *Spirulina platensis* (7.46×10^8 cells/m^3), non-toxic producer and dominant species was *Microcystis aeruginosa* (1.73×10^8 cells/m^3), the toxic producer. The toxins can be harmful to fish's liver in an oxidation pond. The relationship between cyanobacteria blooming and solar radiation (during November 2013 to February 2014) in the oxidation pond of the wastewater treatment system is the main research objective. The net radiometer and spectroradiometer were used to measure solar radiation. Daytime and seasonal variation of net radiation, UV, visible light and infrared including their proportions were used to analyze the relationship. Daytime net radiation in Cyanobacteria blooming was continuously increasing during a period were 354.8, 405.4, 417 and 448 w/m^2, respectively that contrasts non-blooming period. Cyanobacteria blooming period and non-blooming period that has the proportion of UV (300 to 380 nm), visible light (381 to 750 nm) and infrared (751 to1140 nm) were stable. Monthly cumulative of net radiation on blooming period that increased from November to February were 26,245.4, 27,488.1, 27,850 and 30,042 w/m^2, respectively. The results showed that the continuously increasing of net radiation over four months and the sharply increasing of UV radiation were the main reasons for the phenomenon.

Keywords: Solar radiation; Cyanobacteria bloom; Oxidation ponds; Community wastewater treatment.

1. Introduction

The Sun is a primary energy source for life on the Earth. The incoming solar radiation energy was classified mainly as visible light, short wave and long wave (Stephen *et al*., 2000; Matzarakis *et al*., 2010; Stephens *et al*., 2012). The solar energy was used by the plant, primary producers for the photosynthesis process. Plant pigment can absorb only light, the wavelength range from 400 to 700 nm (Stephen *et al*., 2000; Muller *et al*., 2015) and used biochemical processes to convert light into energy. The light, wavelength 400-700 nm was called photosynthetically active radiation (PAR) (Lesser and Farrell, 2004; Schouten *et al*., 2007). In addition to terrestrial plants, light also effects on the behavior of aquatic organisms (Longcore and Rich, 2004; Jacovides *et al*., 2015). Light intensity is inversely proportional to distance or depth of water (Figuroa *et al*., 1994; Egiert *et al*., 2012) that affects to a physiological amount of aquatic plants such as phytoplankton and cyanobacteria (Hader *et al*., 2003; Huisman *et al*., 2004; Hader and Sinhab, 2005). UV was used for cyanobacteria's activity such as growth, motility, pigmentation, development, nutrient uptake, survival, and other metabolic processes (Sinha and Hader, 2002; Kumar *et al*., 2003; Rahman and Sundaram, 2014).

Cyanobacteria are a microorganism. It can make and use their own organic food from solar radiation (Gao *et al*.,2007; Mullineaux, 2014;) through photosynthesis process by using pigment such as chlorophyll, carotenoid, phycoerythrin and allophycocyanin (Xing *et al*., 2007; Dartnell *et al*, 2011). The process uses solar energy to reduce $NADP^+$ to NADPH and used in the growth process (Johnson, 2016). The cyanobacteria blooming caused by appropriate of light and nutrient that be the cause of cyanobacteria bloom (Davis *et al*., 2009; Tao *et al*., 2010; Nandini *et al*., 2013). Cyanobacteria bloom has a stage (Hensea and Beckmann, 2010; Oyama *et al*., 2015) that has a major impact on water quality.

The oxidation pond of the wastewater treatment system is located at the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project (The LERD project). This site is located at Ban Laem District, Phetchaburi Province, Thailand. It is used to treat community wastewater from Phetchaburi municipal. The oxidation pond system contains five ponds including sedimentation pond (1^{st} pond), oxidation pond (2^{nd} 3^{rd} and 4^{th} pond) and polishing pond (5^{th} pond) (Pattamapitoon *et al*., 2013). During cyanobacteria blooming, there were dead fishes because Microcystis aeruginosa produced microcystin (hepatotoxin) that effected on fish liver (Srichomphu *et al*., 2015).

In the present work, we study effects of solar radiation on cyanobacteria blooming in oxidation ponds system of community wastewater treatment at the LERD project, Phetchaburi, Thailand. The influence of solar radiation, such as the wavelength and intensity of solar radiation was discussed. The results will be used to control and management of cyanobacteria at the LERD project in the future.

2. Materials and Methods

2.1 Study area

The King's Royally Initiated Environmental Research and Development Project (The LERD project) is one of community wastewater treatment in Thailand (Figure 1). This site is located at Phetchaburi Province, Thailand (latitude 130 02′40″ to 130 03′20″ N; longitude 1000 05′10″ to 1000 06′05″ E or UTM 1442240 to 1443480 N and 0617780 to 0619271 E).

2.2 Radiation data analyses

Solar radiation was measured as net radiation and solar spectrum at the study area. The net radiometer, CNR4 model was used to measure incoming and outgoing solar radiation. The spectroradiometer, MS700 model was used for the solar spectrum (wavelength 300 to1150 nm) (Figure 2). The measured solar radiation data can be divided into two periods, non-cyanobacteria blooming period and cyanobacteria blooming period, the year 2013-2014. The non-blooming period was classified in the year 2011 to 2013 and 2014 to 2015.

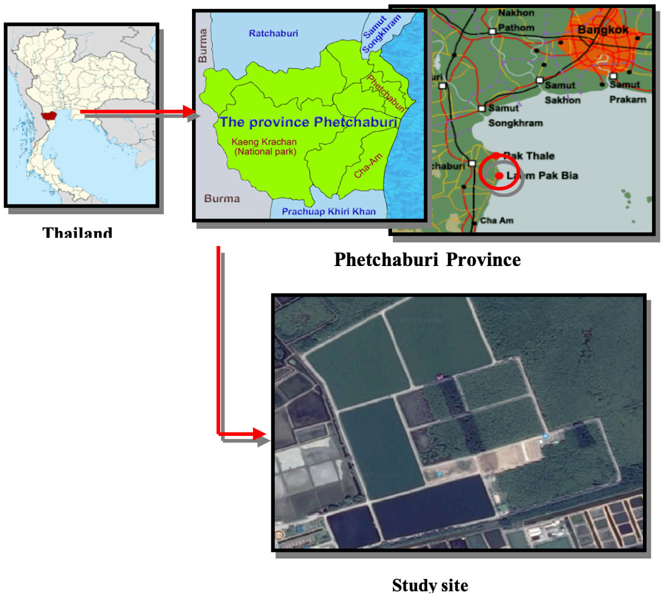


Figure 1. Study area at the LERD project

Figure 2. Net radiometer (CNR4) and Spectroradiometer (MS700)

2.3 Water Sample analyses

Collection and Analyses of water samples in oxidation ponds 1 to 5 of the LERD project was in the period of January and February 2014. The water samples consisted of water quality and nutrient concentrations. Three parameters of water quality were measured on-site such as temperature (Temp.), dissolved oxygen (DO) and pH. Five parameters of nutrient concentrations were measured in the laboratory such as biochemical oxygen demand (BOD), total Kjeldahl nitrogen (TKN), ammonium (NH_4^+), nitrate (NO_3) and total phosphorus (TP). The nutrient concentrations were tested according to the standard methods for the Examination of Water and Wastewater (APHA, AWWA, and WPCF, 2005).

2.4 Cyanobacteria Sampling

Studied of cyanobacteria species and amount were used a phytoplankton net with a mesh size 20 µm sampling down to 30 m height from water surface by collected water sample 10 L with the bottle in January and February 2014. Water sample fixed with 4% Formalin and fined cyanobacteria species and cell counting in a laboratory.

3. Results and Discussion

3.1 Water Sample

During the blooming period, there were significant physical changes in the oxidation ponds such as watercolor, dead fish. Averaged water temperature, dissolved oxygen and pH value were equal to the standard value. Averaged biochemical oxygen demand (BOD) and NH_4 of 1st, 2nd, 3rd and 4th pond were over to the standard value. Total phosphorus of 2nd, 3rd and 4th pond was equal to the standard value. The averaged nutrient concentrations such as TKN, NH_4, NO_3 and TP were 5.9, 1.4, 0.3 and 1.2 mg/L respectively (Table 1).

High cyanobacteria density in blooming period that affected to high DO in oxidation ponds because high photosynthesis activity in daytime that affected to high dissolved oxygen. Averaged BOD in 1st, 2nd, 3rd and 4th pond was high value because microorganism used a lot of oxygen to organic matter degradation. Nitrogen and phosphorus are essential for cyanobacteria growth. The nutrient concentration in oxidation pond came from Petchaburi municipality wastewater, cyanobacteria nitrogen fixation from atmospheric then change to ammonia, nitrite and nitrate respectively and death of cyanobacteria blooms. TKN and TP concentration was highest in 1st oxidation pond that decreased from 1st to 5th pond as digestion of nutrient (nitrogen and phosphorus) by bacteria were 8.6, 5.6, 6.5, 5, 4 mg/L and 2.4, 1.3, 1.2, 0.6, 0.4 mg/L respectively. The NH_4 value similar to TKN and TP was 2.8, 1.2, 1.7, 0.9 and 0.2 mg/L respectively. High cyanobacteria density affected to nutrient concentration in an oxidation pond.

3.2 Cyanobacteria

During cyanobacteria blooming, there were 11 species of cyanobacteria found in 5 pond of wastewater treatment such as *Oscillatoria* sp., *Rhaphidiopsis* sp., *Chroococcus minutes*, *Gloeocapsa* sp., *Spirulina platensis*, *Microcystis aeruginosa*, *Anabaenopsis* sp., *Merismopedia minima*, *M. incerta*, *Cylindrospermopsis philipinensis* and *Spirulina subsalsa* (Table 2). The highest density of cyanobacteria was *Spirulina platensis* in 3rd pond (82.74%) and *Microcystis aeruginosa* in 4th pond (11.05%) respectively. *Microcystis aeruginosa* was found lower than *Spirulina platensis* but it was a toxic producer and caused of fish death.

3.3 Net radiation

Averaged daytime variation of net radiation on non-cyanobacteria blooming period (November 2011 to February 2012, November 2012 to February 2013 and November 2014 to February 2015) and cyanobacteria blooming period (November 2013 to February 2014) were shown a difference between the periods (Figure 3). The daytime net radiation of non- blooming period was varied (Figure 3a, 3b and 3d) but it was continuously increased from November 2013 to February 2014, blooming period. After the blooming period, the daytime net radiation was not continuously increased and showed the same trend as the non-blooming period.

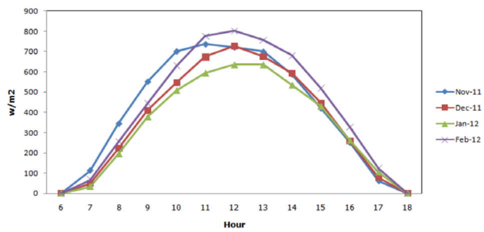
Table 1. Water samples in oxidation pond during cyanobacteria blooming in January and February 2014 at LERD Project, Phetchaburi Province, Thailand.

Parameters	Oxidation 1st pond	Oxidation 2nd pond	Oxidation 3rd pond	Oxidation 4th pond	Oxidation 5th pond
Temp. (23-32[2])	29.4	27.6	27.7	27.6	27.6
DO (>3[2])	8.5	8.7	9.5	9.9	9.7
pH (5.5-9.0[1])	7.5	8.5	8.6	9	9.1
BOD (<20[1])	79.9	27.4	26.8	24.5	19.2
TKN	8.6	5.6	6.5	5	4
NH_4	2.8	1.2	1.7	0.9	0.2
NO_3	0.2	0.3	0.2	0.3	0.3
TP (<2[1])	2.4	1.3	1.2	0.6	0.4

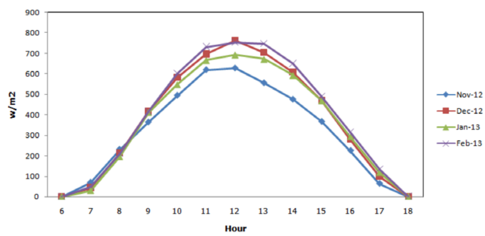
Remarks: [1]The Standard of control drains effluent water from community wastewater treatment system from Ministry of Natural Resources and Environment, Thailand.
[2] The Standard of water quality for aquatic animal life from Department of Fisheries, Thailand.

Table 2. Species and cell counting of Cyanobacteria in oxidation pond (cell/m^3) during cyanobacteria blooming in January and February 2014 at LERD Project, Phetchaburi Province, Thailand.

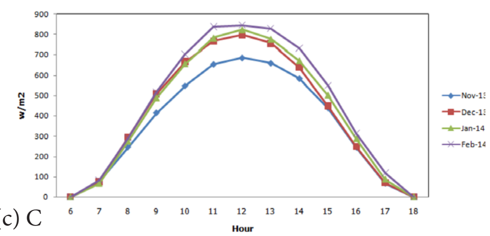
Species	Percentage	Oxidation 1st pond	Oxidation 2nd pond	Oxidation 3rd pond	Oxidation 4th pond	Oxidation 5th pond
Oscillatoria sp.	3.52	1.38x10^6	5.84 x10^7	1.16 x10^7	4.76 x10^6	1.97 x10^5
Rhaphidiopsis sp.	1.26	2.17 x10^7	4.90 x10^6	1.60 x10^4	6.49 x10^4	3.42 x10^5
Chroococcus minutes	0.06	1.12 x10^6	6.53 x10^4	7.76 x10^4	3.24 x10^4	5.85 x10^4
Gloeocapsa sp.	0.01	1.36 x10^5	5.52 x10^4	4.08 x10^4	-	-
Spirulina platensis	82.74	1.09 x10^6	6.67 x10^8	7.46 x10^8	3.76 x10^8	2.84 x10^6
Microcystis aeruginosa	11.05	3.52 x10^4	7.38 x10^5	3.84 x10^7	1.73 x10^8	2.66 x10^7
Anabaenopsis sp.	0.01	-	-	-	-	2.17 x10^5
Merismopedia minima	0.001	-	9.56 x10^3	5.35 x10^3	6.62 x10^3	4.12 x10^3
M. incerta	0.01	6.62 x10^3	-	-	-	1.10 x10^5
Spirulina subsalsa	0.06	-	-	-	-	1.23 x10^6
Cylindrospermopsis philipinensis	1.28	-	-	-	4.66 x10^5	2.71 x10^7



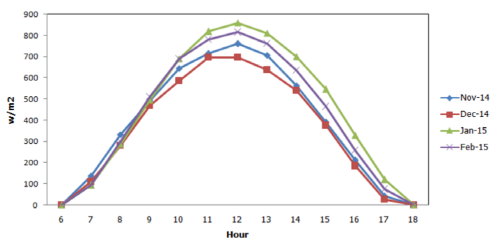
(a) Non-cyanobacteria blooming period (2011-2012)



(b) Non-cyanobacteria blooming period (2012-2013)



(c) Cyanobacteria blooming period (2013-2014)



(d) Non-cyanobacteria blooming period (2014-2015)

Figure 3. Comparison of daytime variation of net radiation on blooming and non-blooming periods at the LERD project

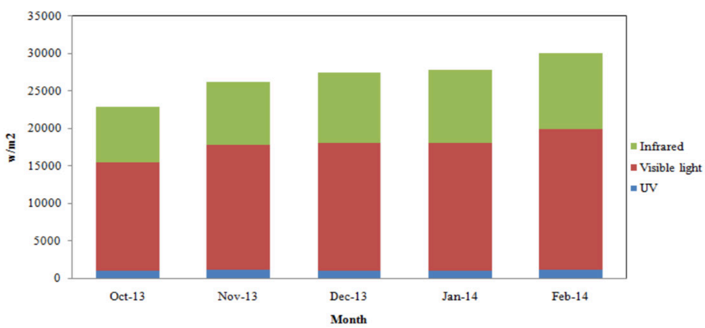


Figure 4. Monthly cumulative of solar spectrum during blooming period at LERD project, (November 2013-Febuary 2014)

On non-blooming period (June to October 2013, rainy season), the averaged daytime radiation were 362.6, 323.7, 368.4, 323.4 and 331.2 w/m^2 respectively. The variation of averaged daytime net radiation caused by moisture and cloud in the atmosphere that make those absorption net radiation and affects less intensity of light in rainy season. Compared to the blooming period, (November 2013 to February 2014, winter season), the averaged daytime net radiations were 354.8, 405.4, 417 and 448 w/m^2, respective. It was continuously increased.

The continuously increasing of average daytime net radiation in figure 3(c) can be considered as cumulative of net solar radiation. The highest monthly cumulative net radiation was found on cyanobacteria blooming period, February 2014 (30,042.1 w/m^2) compared to non-blooming period, November 2011 (30,192.2 w/m^2) and October 2012 (29,068.2 w/m^2) on Figure 4.

On the blooming period, the solar spectrum, was increased as same as cumulative of solar radiation. The solar spectrum is divided into three ranges, ultraviolet wavelength, UV (300 to 380 nm), visible light (381 to 750 nm) and infrared wavelength (751 to 1140 nm). The proportion of the solar radiation spectrum (UV, visible light and infrared) was stable during blooming and non-blooming period. Visible light was strongly related to net radiation.

4. Conclusion

There were 11 species of cyanobacteria during cyanobacteria blooming in the oxidation ponds at LERD project. The dominant species were *Spirulina platensis*, non-toxic producer and *Microcystis aeruginosa*, toxic producer and caused of fish death. In the oxidation pond that has enough nutrient concentration for cyanobacteria growth from community wastewater. The bloom of cyanobacteria depends on external factors. Solar radiation was a significant factor to cyanobacteria blooming. The different solar radiation during blooming and non-blooming period was continuously and sharply increasing of net radiation from November to February. Therefore continuously increasing and sharply increasing of net radiation were key factors for cyanobacteria blooming.

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