A Simple Mathematical Model of Water Quality Control for Recirculating Pond on a Shrimp Farm

Witsarut Kraychang, Sompoom Meechowna, Weerapol Welamas and Nopparat Pochai

***Abstract*— In many countries, shrimp is one of the most valuable export commodities. Shrimp farming raises a number of issues, including shrimp waste contamination, shrimp feed residues, and biochemical reactions in the shrimp pond. In this research, mathematical models were utilized to analyze the water quality in shrimp ponds and wastewater treatment ponds for circulation systems, with BOD serving as a significant indication of water quality. In the circulation system, two separate ponds were investigated: the shrimp pond and the wastewater treatment pond. The shrimp pond was tested for pollutant levels generated by shrimp excretion, shrimp feed residues, and biochemical reactions. A Chaipattana low-speed surface aerator was used to treat the shrimp pond pollutants, and some of the waste was drained to the next pond. The pollutant levels in the treatment pond were investigated. This pond is polluted by sewage from the shrimp pond as well as biological reactions. Lower-efficiency aerators treat the contaminants in the treatment pond, and part of the waste is transferred to the next pond. The advection equation is being used to describe the pollutant concentration in two ponds, and Runge-Kutta order 4 is also being used to determine the approximated solution to the problem. The results of the mathematical model are presented in graphs and tables comparing the pollutant concentrations in many cases. The last section shows an example of wastewater treatment by aerator in a shrimp pond. It was found to reduce the number of days needed for wastewater treatment. The water quality could generate shrimp in this condition, but the water quality could not grow shrimp if the aerator was not turned on the first day of shrimp farming and then turned on the next day. On the first day of shrimp farming, the aerator should not be turned off since the pollutant concentration would be high, making wastewater treatment difficult the next day. In addition, the research showed a maximum five-day reduction in wastewater treatment time (last days of the month). When wastewater is treated every other day, every three days, or every five days, the pollutant concentration must be lower than the minimum necessary for shrimp farming. It can also be used to reduce the cost of water treatment by saving energy.**

***Index Terms*—water quality, shrimp pond, Advection equation, recirculated system**

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I. Introduction

SHRIMP farming is the occupations of Thai farmers because shrimp is an important exported product of Thailand. Shrimp farming has several problems in particular water pollution caused by the excretion from shrimp, residues of shrimp feed and biochemical reaction in shrimp pond. Generally, there are three shrimp farming systems in Thailand including; opened system, closed system, and recirculated system. Almost shrimp farming installs a recirculation system of water treatment and recycle. There are several studies on the environmental impacts from shrimp farming in [1] and [2], which is necessary to control water quality and to reduce environmental pollution. In addition, research studies on factors affecting wastewater quality in shrimp farming in aquaculture, and to assess and to control water quality for shrimp farming gives prawns of good quality [3] and [4]. The private company in Thailand has developed a shrimp farming system for Thai farmers, using a water recycle system without releasing wastewater from the shrimp farm to the environment and keep excess sediment in the farm called the “Zero Discharge”. The zero discharge is the suitable way for water management, which an aerator is used to treat wastewater in this system.

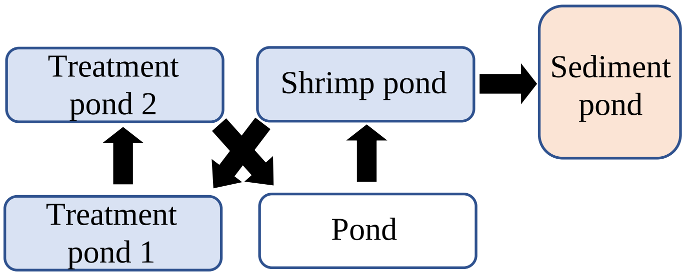

Fig. 1. Recirculation shrimp farming model.

The concept of recirculation shrimp farming model showed in Fig. 1, including;

Step 1: Conveying sediment from shrimp pond to the sediment pond and drain the waste water to the treatment pond 1 and 2 for treatment.

Step 2: After treating the wastewater in treatment pond 1 and 2, it is good quality water and drained to next pond.

Step 3: And this recycle water is used to shrimp pond again.

Water quality measurement in shrimp farming can be performed by collecting samples of water different times; hourly, daily from in shrimp pond for BOD calculation. It is a common metric for water pollution, and it was difficult to get samples because of a highly cost to analyze all of the collected samples and it requires experienced personnel. Mathematical model becomes potentially a valuable tool that could be used to calculate the BOD value in shrimp pond.

Nowadays, researchers use mathematical models to solve real environmental problems and subsequently, to use the results obtained from model to decide on problem solving. For instance, mathematical models were applied to assess the air quality in areas under Bangkok sky train platforms, Thailand in [5]. Moreover, a mathematical model was used to measure air pollutant concentration in industrial areas in [6]. Besides, mathematical models were used to simulate the effect on groundwater quality over long periods of time in [7]. The mathematical model was also used to measure salinity in the Chaophraya river in [8] and also to study the steady infiltration problem in [9]. In addition, there is also several research using mathematical models to measure and assess water quality in [10] and [11] by applying mathematical models to assess the water quality at Nok Phrao Island by assuming observation points. This result used to get a pollutant concentration before and after the implementation of biological treatment from the wastewater treatment station in [12], they use a mathematical model to study the water-quality in the Rama 9 reservoir, Pathum Thani District, Thailand in [13], two mathematical models are used to simulate pollution due to sewage effluent in the uniform reservoir with varied current velocity in [14].

In this research, water quality in shrimp pond and wastewater treatment 1 was determined by analyzing the BOD value, which is an indicator of water pollution. The expected benefit of this research is to apply a mathematical model to control average water quality in shrimp pond for the living of shrimp in pond, it also reduces the cost of wastewater treatment management by using Chaipattana low speed surface aerator,

In this study, the governing equations are proposed for describe the pollutant concentration in shrimp pond and treatment pond 1 by using zero-dimensional first order advection equation and solving the problem by Runge-Kutta order 4, one of the most widely used mathematical problems in the form of first order differential equations [15]. There are several studies using Runge-Kutta order 4 for applying real problem in [16], [17], [18] and [19].

This current study is divided into 5 sections: the first section is the introduction; the second section describes the mathematical model consist of the scope domain and governing equation, advection equation; the third section describes the numerical method, using by Runge-Kutta order 4; the fourth section shows the results and example situation for wastewater treatment by aerator; and the last section is the discussion and conclusion.

II. Mathematical Model

In this section, the governing equations were used to describe the average pollutant concentration in shrimp pond and treatment pond 1 and to set the scope of study.

A. *Recirculated system*

The recirculated system is water recycle system, wastewater from shrimp ponds is released into treatment pond 1 and treatment pond 2 for wastewater treatment by aerator, after that, treated water is stored in pond for recycle of shrimp farming. The scope of this research focuses on shrimp ponds and treatment pond 1, which are important ponds of this system.

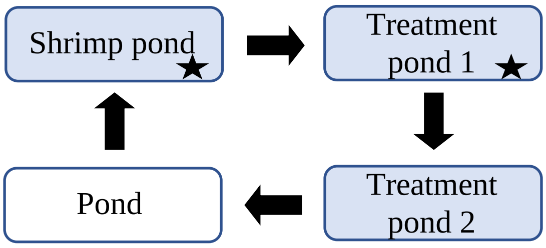

Fig. 2. Scope of study, shrimp pond and treatment pond 1.

B. *Advection equation*

In this section, concerning the use of zero-dimensional first order advection equation with advection term, source term due to biochemical reaction rate of pond, sink term, describe the average pollutant concentration at any time period of 30 days by considering each pond as follows,

a) Advection equation of shrimp pond

The zero-dimensional first order advection equation used to describe the average pollutant concentration in shrimp pond. Equation consists of transient term, reaction term due to biochemical of shrimp pond and reduce pollution term are water treatment term by Chaipattana low speed surface aerator and removal term due to drainage water from shrimp pond to treatment pond 1 by using the following equation;

$$v_1(t)\frac{dC_1(t)}{dt} = R_1(t)C_1(t) - Q_1(t) - S_1(t)C_1(t)\,, \qquad (1)$$

where

$v_1(t)$ is volume of shrimp pond,

$C_1(t)$ is pollutant concentration average of shrimp pond,

$R_1(t)$ is biochemical reaction rate of shrimp pond,

$Q_1(t)$ is water treatment term by Chaipattana low speed surface aerator,

$S_1(t)C_1(t)$ is removal term due to drainage water from shrimp pond to treatment pond 1,

b) Advection equation of treatment pond 1

The zero-dimensional first order advection equation used to describe the average pollutant concentration in treatment pond 1. Equation consists of transient term, reaction term due to biochemical of shrimp pond and reduce pollution term are water treatment term by Chaipattana low speed surface aerator and removal term due to drainage water from treatment pond 1 to treatment pond 2, and provide the following equation;

$$v_2(t)\frac{dC_2(t)}{dt} = R_2(t)C_2(t) - Q_2(t) + A_1(t)C_1(t) - S_2(t)C_2(t) \qquad (2)$$

where

$v_2(t)$ is volume of treatment pond 1,

$C_2(t)$ is pollutant concentration average of treatment pond 1,

$R_2(t)$ is biochemical reaction rate of treatment pond 1,

$Q_2(t)$ is water treatment term by Chaipattana low speed surface aerator,

$S_2(t)C_2(t)$ is removal term due to drainage water from treatment pond 1 to treatment pond 2,

$A_1(t)C_1(t)$ is term of wastewater released from shrimp pond to treatment pond 1,

III. NUMERICAL METHOD

In this section, the numerical method was used to solve the zero-dimensional first order advection equation in previous section. This section is divided into 3 part: the first part is Runge-Kutta order 4, which is used for solving advection equation; the second part, apply Runge-Kutta order 4 to (1); the last part, apply Runge-Kutta order 4 to (2).

A. The Fourth order Runge-Kutta method (RK4)

The formula for the fourth order Runge-Kutta method (RK4) is given below. Consider the first order ordinary differential equation

$$y' = f(t,y) \text{ with initial condition } y(t_0) = a\,. \qquad (3)$$

Define Δt to be the step size of time t and $t_i = t_0 + i\Delta t$, we have the following formula, let $y_i = y(t_i)$ and $y_0 = a$,

$$y_{i+1} = y_i + \frac{1}{6}\left(k_1 + 2k_2 + 2k_3 + k_4\right) \qquad (4)$$

where

$$k_1 = \Delta t\, f\left(t_i, y_i\right),$$
$$k_2 = \Delta t\, f\left(t_i + \frac{\Delta t}{2}, y_i + \frac{k_1}{2}\right),$$
$$k_3 = \Delta t\, f\left(t_i + \frac{\Delta t}{2}, y_i + \frac{k_2}{2}\right),$$
$$k_4 = \Delta t\, f\left(t_i + \Delta t, y_i + k_3\right).$$

B. Numerical method for advection equation of shrimp pond

Rearrange the (1), we have

$$\frac{dC_1(t)}{dt} = \frac{R_1(t)C_1(t) - Q_1(t) - S_1(t)C_1(t)}{v_1(t)}\,, \qquad (5)$$

where $f(t, C_1(t)) = \dfrac{R_1(t)C_1(t) - Q_1(t) - S_1(t)C_1(t)}{v_1(t)}$ and initial condition of pollutant concentration in shrimp pond $C_1(t_0) = c_0$ and apply RK4 to (5), we have

$$\left(C_1\right)_{i+1} = \left(C_1\right)_i + \frac{1}{6}\left(k_1 + 2k_2 + 2k_3 + k_4\right) \qquad (6)$$

where

$$k_1 = \Delta t\, f\left(t_i, \left(C_1\right)_i\right),$$
$$k_2 = \Delta t\, f\left(t_i + \frac{\Delta t}{2}, \left(C_1\right)_i + \frac{k_1}{2}\right),$$
$$k_3 = \Delta t\, f\left(t_i + \frac{\Delta t}{2}, \left(C_1\right)_i + \frac{k_2}{2}\right),$$
$$k_4 = \Delta t\, f\left(t_i + \Delta t, \left(C_1\right)_i + k_3\right).$$

C. Numerical method for advection equation of treatment pond 1

Rearrange the (2), we have

$$\frac{dC_2(t)}{dt} = \frac{R_2(t)C_2(t) - Q_2(t) + A_1(t)C_1(t) - S_2(t)C_2(t)}{v_2(t)}\,, \qquad (7)$$

where

$$f(t, C_2(t)) = \frac{dC_2(t)}{dt} = \frac{R_2(t)C_2(t) - Q_2(t) + A_1(t)C_1(t) - S_2(t)C_2(t)}{v_2(t)}$$

and initial condition of pollutant concentration in treatment pond 1 $C_2(t_0)=c_0$ and apply RK4 to (5), we have

$$\left(C_2\right)_{i+1}=\left(C_1\right)_i+\frac{1}{6}\left(k_1+2k_2+2k_3+k_4\right) \quad (8)$$

where

$$k_1=\Delta t\ f\left(t_i,\left(C_2\right)_i\right),$$
$$k_2=\Delta t\ f\left(t_i+\frac{\Delta t}{2},\left(C_2\right)_i+\frac{k_1}{2}\right),$$
$$k_3=\Delta t\ f\left(t_i+\frac{\Delta t}{2},\left(C_2\right)_i+\frac{k_2}{2}\right),$$
$$k_4=\Delta t\ f\left(t_i+\Delta t,\left(C_2\right)_i+k_3\right).$$

IV. NUMERICAL RESULTS

In this section, various results reported in a table and a comparison graph in many cases, by considering shrimp pond and treatment pond 1. The mean pollutant concentration in shrimp pond and treatment pond 1 were 5 mg/l and 3 mg/l (BOD), respectively, which two ponds have a wastewater treatment system inside the pond using Chaipattana low speed surface aerator and every 7 days, the wastewater from shrimp pond is drained to treatment pond 1 and from treatment pond 1 to treatment pond 2, by calculating the mean pollutant concentration at any time period of 30 days

A. Pollutant concentration in shrimp pond

The results in this section showed a comparing graph and table of pollutant concentration in two cases as mentioned following.

a) Wastewater treatment by aerator

The trend of pollutant concentration from mathematical model decreased when treating wastewater by the Chaipattana low speed surface aerator with the different efficiency in the shrimp pond, and the parameter $Q=5.00$, $Q=5.15$, $Q=5.30$, $Q=5.45$ and $Q=5.60$ with $R=1.04$. In this situation, there is no wastewater drainage to treatment pond 1. It was found that case $Q=5.00$ and $Q=5.15$ was ineffective in treating the wastewater in the shrimp pond for shrimp survival in Fig. 3, on the other hand, when $Q=5.30$, $Q=5.45$ and $Q=5.60$, the pollutant concentration at time period of 1 month has good efficiency in treating wastewater in shrimp pond.

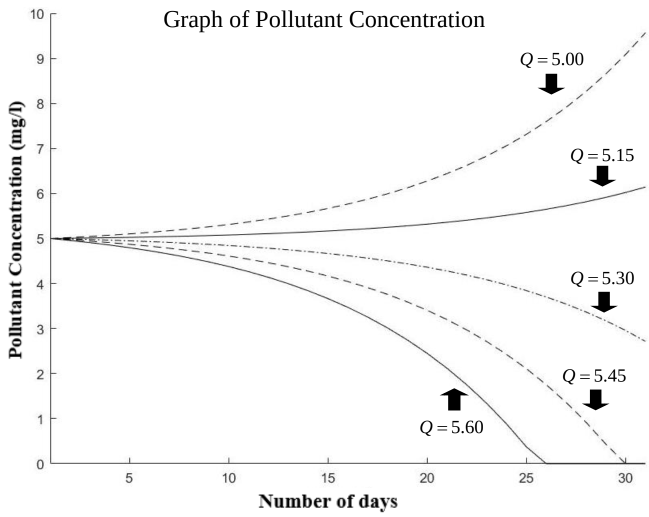

Fig. 3. The pollutant concentration in shrimp pond in case different efficiency of aerator

The drainage of wastewater from shrimp pond to treatment pond 1, caused the volume of water in shrimp pond to decrease and the pollutant concentration has changed. Mathematical model in these two cases are studied: the first case studied the pollutant concentration when the volume of water does not change, $V(t)=14,000$ and using aerator for treating wastewater in shrimp pond, the constant volume function means the rate of water flowing out and water flow in are equal; the second case studied the pollutant concentration when volume of water has changed, $V(t)=14000-2500\sin(t)$ with variable time t, for parameters $R_1=1.02$ and $Q_1=5.3$ as shown in Fig. 4.

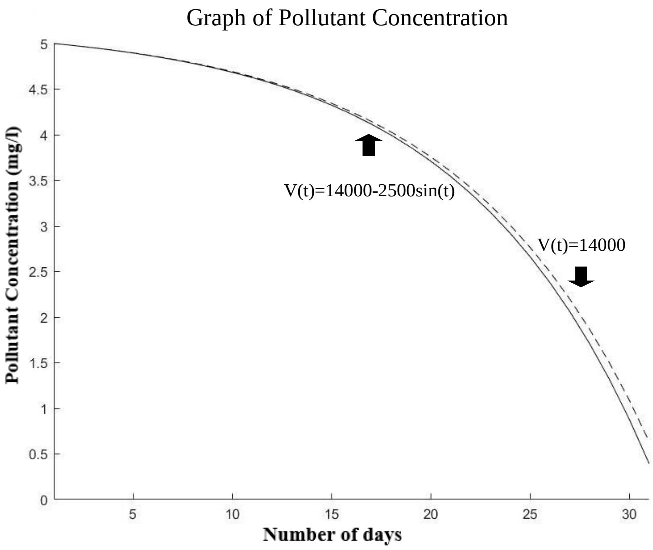

Fig. 4. The comparison of pollutant concentration of the shrimp ponds in the case of an increase or decrease in the volume of the water

b) Wastewater treatment by aerator and drainage

The trend of pollutant concentration from mathematical model decreased when treating wastewater by the Chaipattana low speed surface aerator and the wastewater is drained from the shrimp pond with parameters $R_1=1.03$ and $Q_1=4.4$ shown in Fig. 5.

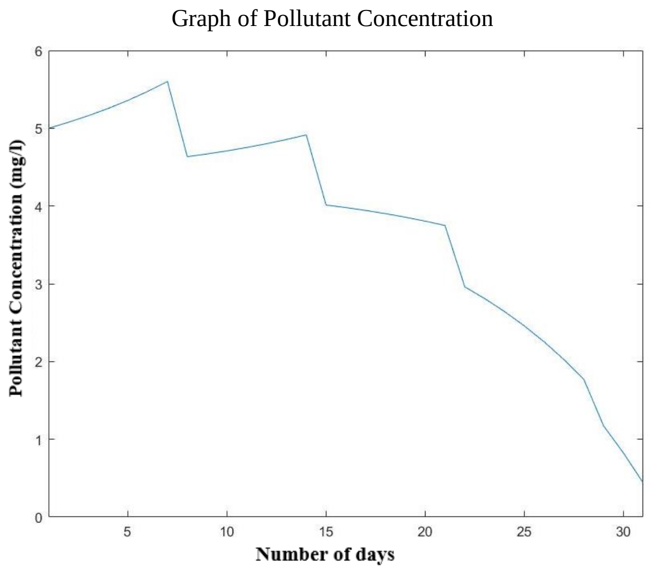

Fig. 5. The pollutant concentration in shrimp pond in case of biochemical reaction R = 1.03

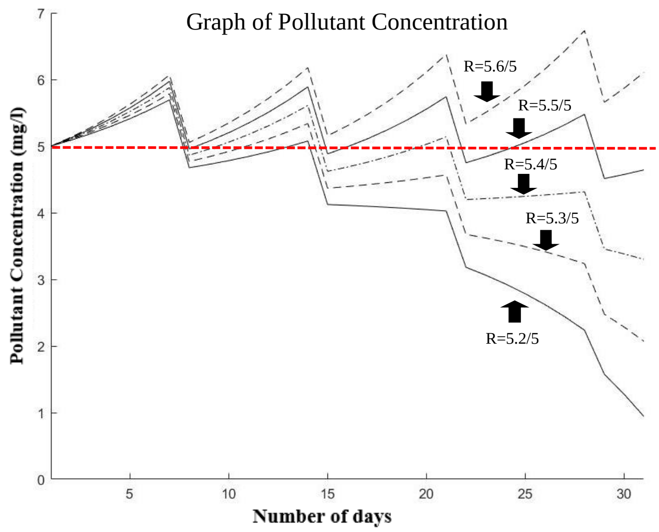

Fig. 6. The comparison of pollutant concentration in shrimp pond in many cases of biochemical reaction

Fig. 6. represented the efficiency of the wastewater treatment in shrimp pond by aerator and wastewater drainage every week over 1 month to the treatment pond, in term of the biochemical reaction rate of shrimp pond (R_1) has changed, initial of pollutant concentration within pond 5 mg/l and parameter $Q_1 = 4.4$. The red dotted line is the indicator of wastewater treatment in shrimp pond when the parameter R_1 is changed, from the graph, it can be observed that the parameter $R_1 = 1.1$, which has the efficiency of treating wastewater in shrimp pond that can also treated the pollutant concentration below the red dotted line within a period of month but the parameter $R_1 = 1.12$, it was observed that the pollutant concentration at day 30 was higher than the first day (above the red dotted line) as shown in more details in Table I, which showing results at day 5, 10, 15, 20, 25 and 30. These results are informative for making decisions about improving the efficiency of wastewater treatment: increasing the frequency of draining water from the shrimp pond to the treatment pond, increasing the number of aerators

TABLE I
POLLUTANT CONCENTRATION IN SHRIMP POND.

Term R_1	Pollutant Concentration (mg/l) Date: 5	10	15	20	25	30
5.6/5	5.4107	4.7816	4.1226	4.0462	2.7835	1.2765
5.5/5	5.4641	4.9185	4.3674	4.5243	3.4905	2.2849
5.4/5	5.5180	5.0583	4.6207	5.0266	4.2458	3.3817
5.3/5	5.5723	5.2010	4.8828	5.5545	5.0524	4.5736
5.2/5	5.6271	5.3468	5.1542	6.1088	5.9132	5.8674

Fig. 7. showed an example of the comparison curve in case parameter $Q_1 = 4.5$, $Q_1 = 4.6$, $Q_1 = 4.7$, $Q_1 = 4.8$ and $Q_1 = 4.9$ when $R_1 = 1.12$, it was found that after 1 month the pollutant concentration in shrimp pond was lower than the initial pollution and day 30 for $Q_1 = 4.9$, the pollution is reduced to zero as shown in more details in Table II.

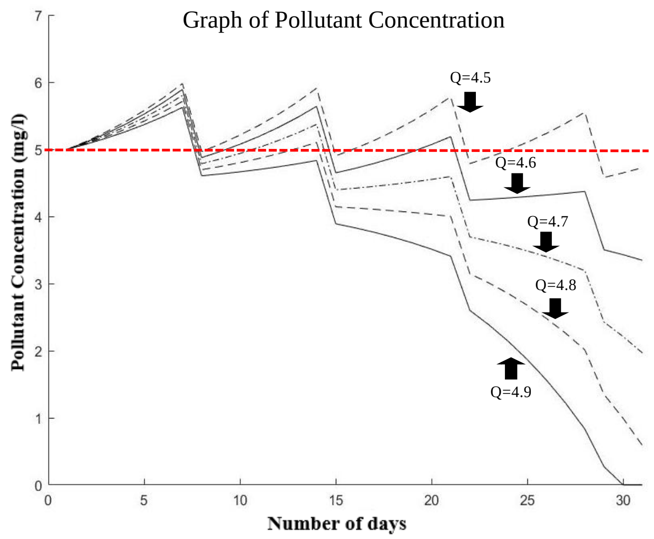

Fig. 7 The comparison of pollutant concentration in shrimp pond in many cases of water treatment term

TABLE II
POLLUTANT CONCENTRATION IN SHRIMP POND..

Term Q_1	Pollutant Concentration (mg/l) Date: 5	10	15	20	25	30
4.5	5.5748	5.2101	4.9012	5.5893	5.1039	4.6481
4.6	5.5226	5.0734	4.6482	5.0697	4.2946	3.4289
4.7	5.4703	4.9367	4.3953	4.5502	3.4853	2.2096
4.8	5.4181	4.8000	4.1423	4.0306	2.6760	0.9903
4.9	5.3658	4.6633	3.8893	3.5111	1.8667	0.0000

B. *Pollutant concentration in treatment pond*

Factors contributing to the increase in the pollutant concentration in treatment pond are including wastewater drained from shrimp pond and biochemical reaction rate of treatment pond. The wastewater treatment in this pond uses an aerator, which is of lower quality than shrimp pond due to the low pollutant concentration. The results in this section are presented by a comparison graph of pollutant concentration in different cases with a table showing at day 5, 10, 15, 20, 25 and 30 respectively.

a) Change of biochemical reaction rate

The initial pollutant concentration of 3 mg/l, define the parameters of shrimp pond $R_1 = 1.04, Q_1 = 4.4$ and parameters of treatment pond $R_2 = 1.04, Q_2 = 4.22$ with the removal term was due to drainage water from treatment pond to next pond equal 1, which drainage every week over 1 month as shown in Fig. 8 and Fig. 9 with Table IV.

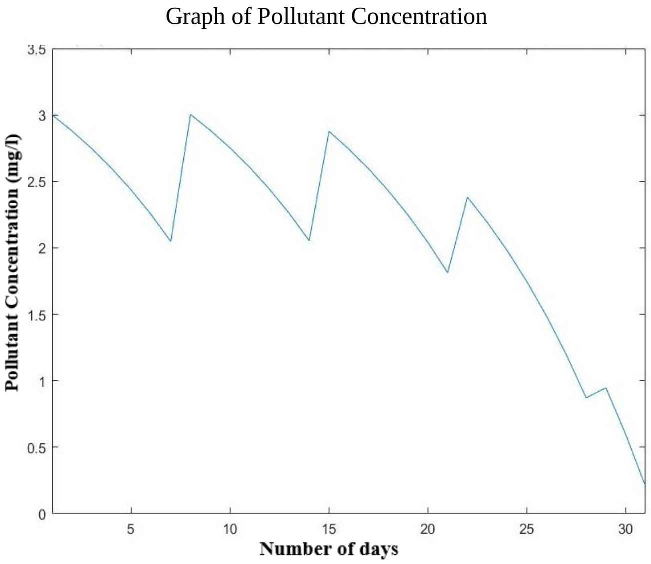

Fig. 8. The pollutant concentration in treatment pond in case of biochemical reaction R = 1.04

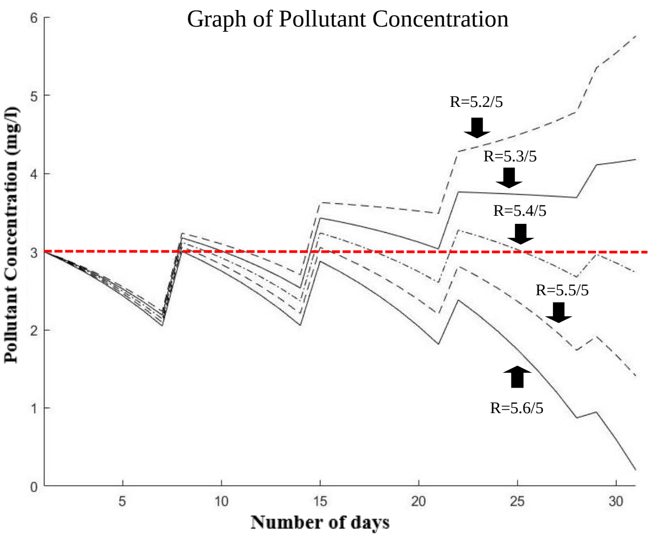

Fig. 9. The comparison of pollutant concentration in treatment pond in many cases of biochemical reaction

TABLE IV
POLLUTANT CONCENTRATION IN TREATMENT POND..

	Pollutant Concentration (mg/l) Date					
Term R2	5	10	15	20	25	30
5.2/5	2.4351	2.7515	2.8763	2.0408	1.7468	0.5962
5.3/5	2.4636	2.8350	3.0540	2.3819	2.3633	1.6759
5.4/5	2.4923	2.9204	3.2382	2.7413	3.0241	2.8547
5.5/5	2.5213	3.0077	3.4293	3.1196	3.7316	4.1402
5.6/5	2.5505	3.0968	3.6273	3.5179	4.4888	5.5402

b) Change of water treatment term by aerator

The parameters of shrimp pond were $R_1 = 1.04$, $Q_1 = 4.4$ and parameters of treatment pond $R_2 = 1.12$. The pollutant concentration in treatment pond when a quality of aerator $Q_2 = 4.15$, $Q_2 = 4.25$ $Q_2 = 4.35$, $Q_2 = 4.45$ and $Q_2 = 4.55$ has shown in Fig. 10 and Table V, found that the pollutant concentration in the case of $Q_3 = 4.35$, $Q_2 = 4.45$ and $Q_2 = 4.55$ was lower than initial pollutant concentration 3 mg/l after 1 month.

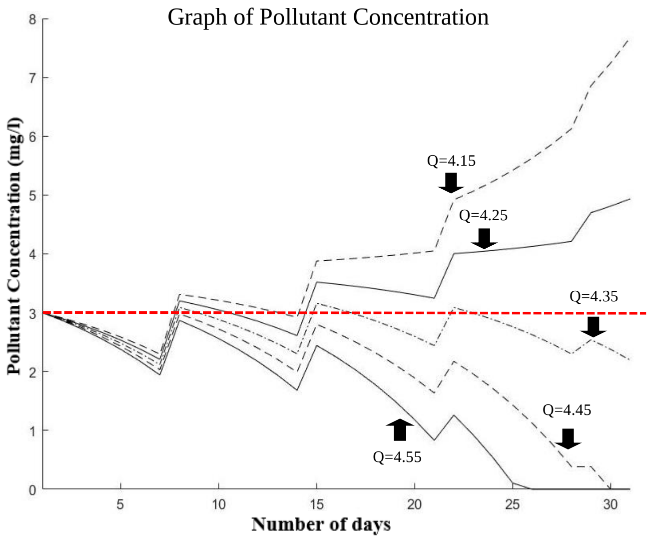

Fig. 10. The comparison of pollutant concentration in treatment pond in many cases of water treatment term

TABLE V
POLLUTANT CONCENTRATION IN TREATMENT POND..

	Pollutant Concentration (mg/l) Date					
Term Q2	5	10	15	20	25	30
4.15	2.5871	3.2106	3.8784	4.0131	5.4186	7.2428
4.25	2.5348	3.0481	3.5197	3.3056	4.0904	4.8105
4.35	2.4826	2.8856	3.1611	2.5981	2.7622	2.3782
4.45	2.4303	2.7230	2.8024	1.8905	1.4340	0.0000
4.55	2.3780	2.5605	2.4438	1.1830	0.1058	0.0000

c) Change of parameter of drainage

The behavior of pollutant concentration in shrimp pond was studied when change of parameter $S_1 = 0$, $S_1 = 0.5$, $S_1 = 1.0$, $S_1 = 1.5$ and $S_1 = 2.0$ shown in Fig. 11 and Table VI, it found the pollutant concentration in case $S_1 = 2.0$ was lower than initial pollutant concentration 5 mg/l after 1 month.

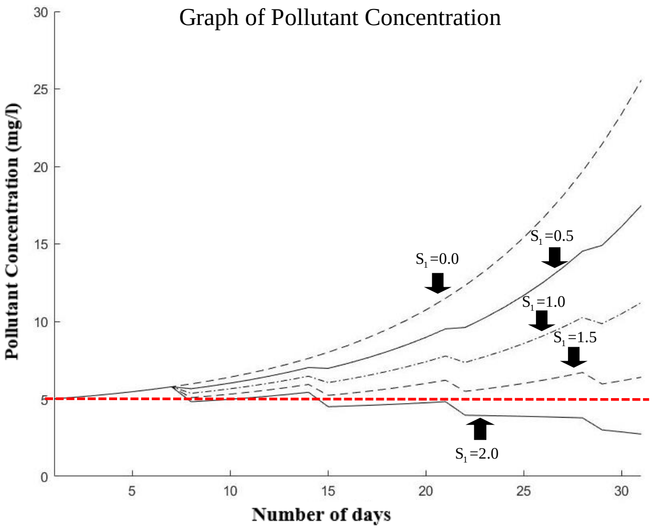

Fig. 11. The comparison of pollutant concentration in shrimp pond in many cases of removal term S_1

TABLE VI
POLLUTANT CONCENTRATION IN TREATMENT POND..

Pollutant Concentration (mg/l) Date						
Term S_1	5	10	15	20	25	30
0.0	5.4621	6.4009	8.0037	10.7399	15.4112	23.3861
0.5	5.4621	6.0165	6.9677	8.9712	11.6764	16.1213
1.0	5.4621	5.6516	6.0451	7.3962	8.5712	10.4943
1.5	5.4621	5.3052	5.2243	5.9949	5.9977	6.1671
2.0	5.4621	4.9764	4.4946	4.7492	3.8725	2.8690

C. *Example of Situation of discontinuity wastewater treatment by aerator*

In this section, the pollution concentration in shrimp pond has been considered with discontinuity wastewater treatment by aerator over 1 month (somedays without wastewater treatment) in closed and no wastewater drainage from shrimp pond to treatment pond, from Fig. 12 showed the different cases of pollutant concentration with using aerator 15 days in 1 month for wastewater treatment, set to initial pollution in pond 5 mg/l, quality of aerator $Q = 4.6$ and assumed the standard of pollution for shrimp farming less than 6.5 mg/l (under the red dotted line). The first case, there are 15 days of wastewater treatment, every other day in treatment, staring the first day of month. Second case, every other three day in treatment, staring the three days of month. Third case, every other five day in treatment, staring the five days of month. Forth case, every other half month in treatment, staring the fifteen days of month. Last case, every day in treatment. It found for first case to forth case, pollution in shrimp pond over the allowed standard.

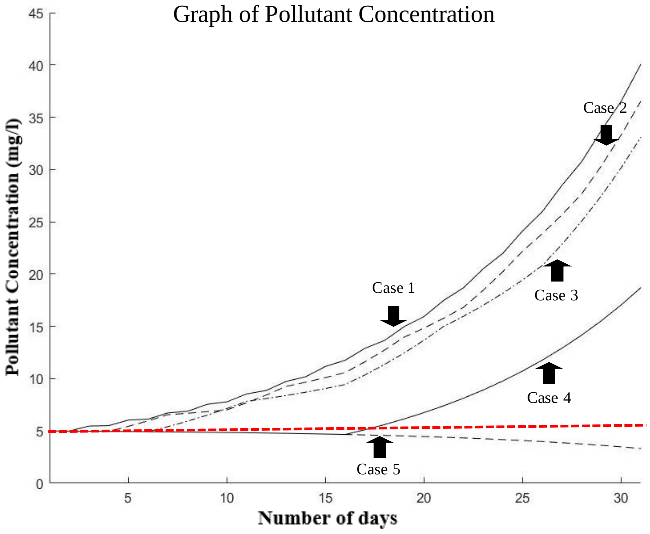

Fig. 12. The pollutant concentration in shrimp pond with five situations of wastewater treatment by aerator

From Fig. 13 showed that many cases of reduction number of days for wastewater treatment for the water quality in shrimp pond, which can do shrimp farming. The first case, there is wastewater treatment every day, except the first day of the month. The second case, there is wastewater treatment every day, except on the 20th, 21st and 30th day of the month. The third case, there is wastewater treatment every day, except on the 26th to 30th day of the month. The last case, there is wastewater treatment every day. It was found that in various cases except first case, the pollutant concentration under the red dotted line, which this condition keeps the shrimp alive, and able to reduce wastewater treatment up to five days (in third case), thus saving the cost o treatment.

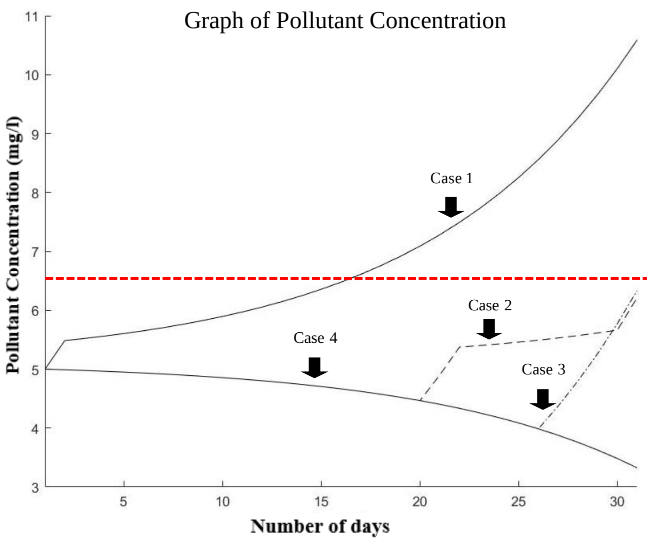

Fig. 13. The pollutant concentration in shrimp pond with four situations of wastewater treatment by aerator

V. Discussion and Conclusion

The mathematical model will be applied in this research to assess the effectiveness and duration of treating waste water with the Chaipattana low-speed surface aerator in order to determine a water quality standard for recirculated shrimp framing. The results in sections 4.1–4.2 showed the Chaipattana low speed surface aerator's efficiency in reducing pollution concentrations. The results in section 4.3 were utilized to save energy costs by reducing the number of days spent treating wastewater.

This requirement keeps the shrimp alive in the mathematical model. On the first day of shrimp farming, the aerator should not be turned off since the pollutant concentration would be high, making wastewater treatment difficult the next day. In addition, the study concluded a maximum five-day reduction in wastewater treatment time (last days of the month). When wastewater is treated every other day, every three days, or every five days, the pollutant concentration must be lower than the minimum necessary for shrimp farming. It can also be used to save energy and lower the cost of water treatment.

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