Carbonaceous biochemical oxygen demand and nitrification oxygen demand of the sediments of *Penaeus monodon* culture ponds

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Abstract

Five-day carbonaceous biochemical oxygen demand ($CBOD_5$) of *Penaeus monodon* pond sediments varied between 10.0 and 40.8 mg/g dry weight. Ultimate carbonaceous BOD of the sediments varied between 16.3 and 61.5 mg/g dry weight. Average $CBOD_5$ of the sediments was 23.2 mg/g dry weight and average ultimate carbonaceous BOD of the sediment was 33.1 mg/g dry weight. $CBOD_5$ of the sediments were 64.9 to 84.7 percent of ultimate CBOD. Rate of biochemical oxidation (k) of shrimp pond sediments varied between 0.09 and 0.15 per day with an average k value of 0.11. Nitrification oxygen demand of shrimp pond sediments varied between 0 and 1.0 mg/g dry weight at 5 days, 2.0 and 4.8 mg/g at 10 days and 4 and 5.6 mg/g at 20 days. Combined oxygen demand of shrimp pond sediments varied between 11.0 and 35.4 mg/g at 5 days, 14.7 and 47.8 mg/g dry weight at 10 days, and 17.7 and 55.1 mg/g dry weight at 20 days. Average twenty-day nitrification oxygen demand of shrimp pond sediments was 5.8 mg/g dry weight. At 20 days, nitrification oxygen demand were 15.6 to 25.6 percent of combined oxygen demand. Results of laboratory scale investigation indicated that aeration of overlying water together with periodically stirring of the sediment can significantly increase reduction rate of BOD_5 of shrimp pond sediments.

Introduction

Major sources of sediment in aquaculture ponds are suspended soil particles in inflowing water, manures and feed added to ponds to promote aquatic animal production, and sediment produced internally by biological activity and management procedures. Organic sediment in ponds originates primarily from plankton. In intensive shrimp culture, uneaten feed and shrimp feces become major sources of organic sediment. Other sources are manure application, and higher aquatic vegetation. When shrimp are stressed by disease or poor environmental conditions high percentage of the feed offered may not be consumed. Nutrients added to ponds in inorganic fertilizers, manures, aquatic animal excrement, and uneaten feed stimulate phytoplankton productivity. Boyd demonstrated that each ton of fish production resulted in the production of about 2.5 tons of dry organic matter in phytoplankton(Boyd, 1985) The life span of phytoplankton is only one to two weeks, and dead cells settle to the pond bottom.

In intensive culture of shrimp, large amount of feed is left in the ponds as uneaten feed. Shrimp feces also contain organic matter that is not utilized by shrimp. It is calculated that only small portion, 11.7 to 13.5 percent, of given feed are converted to shrimp fresh and large portion, 61.7 to 68.1 percent, are leftover in the ponds as feces and shrimp molt. Some parts of the feed, 18.4 to 25.0 percent, is utilized for energy through respiration(Ruttanagosrigit, 1997). Feed conversion ratio (FCR) of the intensive culture of *Penaeus monodon* are between 1.5-1.8 (Lie, 1983; Chen et al, 1989; Muthuwan, 1991). However, if high stocking density is used, feed conversion ratio may increase to the level of 2.0-3.0 (Boyd, 1989). Nutrient released from decomposed feed will trigger phytoplankton bloom and add up organic matter into the pond system(Boyd, 1992)..

According to Tanwilai and Chaiyakum (1993), twenty one tons of sediment were produced in one production cycle of 0.8 ha intensive shrimp culture pond. The sediment contained 13.6 mg/kg hydrogen sulfide, 45.9 mg/kg ammonia, 0.2 mg/kg nitrite, 0.4 mg/kg nitrate, 1.2 mg/kg phosphate, and 16.0 mg/kg organic matter. Musig and Yuttaraksanukul (1991) reported that sediments of *Penaeus monodon* grow-out ponds contained 3.76-4.22 percent organic matter, 19.3-21.4 mg/g BOD_5, and 40.2-56.4 mg/g COD. Boyd, et al (1994) reported that sediment in recently drain shrimp pond contained 1.9 percent organic matter and 890 ppm total nitrogen. Samples of sediment in recently drained ponds had greater concentrations of all chemical substances than new pond soils. The increase in organic matter, nitrogen, and phosphorus resulted from residues of feed, shrimp feces, dead plankton, and, possibly, manures and chemical fertilizers.

The accumulation of sediment enriched with nutrients and organic matter is thought to be a major factor causing the intensification of management in old ponds. In intensive shrimp farming, farmers may remove sediment from ponds after each crop. In some areas, shrimp farmers used high-pressure water jets to resuspend sediment and wash it out of ponds. Some shrimp farmers dry ponds and excavate sediment between crops.

In Thailand, the disposal of sediment from shrimp ponds into surrounding water bodies is inhibited and shrimp farms with farming area exceed 8 ha have to allocate at least 10 percent of farm area for the disposition and the treatment of the sediment.

The biochemical oxygen demand (BOD) test is a bioassay procedure involving the measurement of oxygen consumed by living organisms, mainly bacteria, while utilizing the organic matter present in a waste, under conditions as similar as possible to those that occur in nature. The BOD test may be considered as a wet oxidation procedure in which the living organisms serve as the medium for oxidation of the organic matter to carbon dioxide and water. A quantitative relationship exists between the amount of any given organic compound to carbon dioxide, water, and ammonia. On the basis of this relationship, it is possible to interpret BOD data in terms of organic matter, as well as the amount of oxygen used during its oxidation.

The nitrifying bacteria, which oxidize non-carbonaceous matter for energy, are usually present in relative small numbers in untreated domestic sewage, and their reproductive rate at 20°C is such that the populations do not become sufficiently large to exert an appreciable demand of oxygen until about 8 to 10 days have elapsed in the regular BOD test(Sawyer et al, 1994). Once the organisms become established, they oxidize nitrogen in the form of ammonia to nitrite and nitrate in the amount that introduce serious error into BOD work.

BOD_5 has been included in parameters for shrimp pond effluent standard and BOD_5 measurement has been widely practice to determine pond water quality and pond eflluent quality. BOD_5 measurement also has been practice to determine the degree of organic pollution in pond bottom soils and pond sediments.

This investigation was carried out to study the nature of the decomposition of organic matter in the sediments of *Penaeus monodon* culture ponds by studying biochemical oxygen demand of shrimp pond sediments. Nitrification oxygen demand of the sediments were also investigated. The study was also done to investigate the effect of overlying water aeration and sediment stirring on the reduction rate of BOD_5 of shrimp pond sediments.

Materials and Methods

Biochemical oxygen demand of shrimp pond sediments were studied using sediments from intensive culture ponds from 5 shrimp farms in Rayong and Chantaburi provinces. The sediments were collected and carbonaceous biochemical oxygen demand and combined oxygen demand of each sediment were measured at 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14, 16, 18, and 20 days using dilution method (APHA, AWWA and WEF, 1998). Carbonaceous biochemical oxygen demand were measured by inhibiting nitrification by the application of a nitrification inhibitor, TCMP [2-chloro-6,(trichloromethyl) pyridine] (APHA, AWWA and WEF, 1998).

Nitrification oxygen demand was calculated by subtracting carbonaceous oxygen demand from combined oxygen demand. Ultimate carbonaceous BOD were estimated using Fujimoto methods(Fujimoto, 1961). Rate of biochemical oxidation were calculated from following equation(Hammer and Hammer, 1969);

$$y = L(1-10^{-kt})$$

where L = Ultimate carbonaceous BOD (mg/l)
y = BOD_5 (mg/l)
t = 5 days
k = rate of biochemical oxidation(per day)

The study of the effect of aeration of overlying water and periodically stirring of the sediment on BOD_5 of shrimp pond sediments were conducted in laboratory scale experiments. The study was done in round plastic containers, 15.5 cm in diameter and 20 cm. height. Sediment samples were put into the containers to get sediment layer of 3 cm thick. Then 15 ppt water was added to the volume of 10 cm above sediment surface. Shrimp pond sediments from 2 shrimp farms in Chantaburi province were used for this study. Treatments included control and treatment with water aeration and sediment stirring. Aeration was provided by air-compressor through air-stone. Sediment stirring was done daily. Five replications were set for each treatment. BOD_5 of the sediments in each treatment unit were measured periodically for 7 days. Five replications were set for each treatment. Data were analyzed statistically to study the effect of aeration on reduction rate of BOD_5 of the sediments.

The analysis of the sediment quality were done according to the methods recommended by APHA, AWWA, and WEF (1998). BOD of the sediments were analyzed by dilution method. Carbonaceous oxygen demand was measured by inhibiting nitrification using 2-chloro-6-(trichloro methyl) pyridine (TCMP) (APHA, AWWA, and WEF, 1998).

Results

Five-day carbonaceous biochemical oxygen demand ($CBOD_5$) of shrimp pond sediments varied between 10.0 and 40.8 mg/g dry weight and ultimate carbonaceous biochemical oxygen demand of the sediment varied between 16.3 and 61.5 mg/g. Five-day biochemical oxygen demand were 64.9 to 84.7 percent of ultimate biochemical oxygen demand. Average BOD_5, BOD_{10} and BOD_{20} of shrimp pond sediments were 23.2, 29.5 and 31.1 mg/g, respectively. Ten-day Carbonaceous biochemical oxygen demand were 76.0 to 100 percent of ultimate CBOD and 20-day carbonaceous oxygen demand were 87.5 to 100 percent of ultimate BOD (Table 1).

The BOD_5 values of the sediments were 64.9 percent of ultimate BOD when k values was 0.09 and increased to 70.8 and 84.7 percent of ultimate BOD when k values were 0.11 and 0.15, respectively . Average ultimate BOD of shrimp pond sediment was 33.1 mg/g. The rate of biochemical oxidation (k) of the sediments varied between 0.09 and 0.15 with average k value of 0.11 (Table 1).

There was no nitrification oxygen demand in two shrimp pond sediments at day 5 but in other two shrimp pond sediments, nitrification oxygen demand were detected at low level of 0.4-1.0 mg/g or about 1.4-2.8 percent of combined oxygen demand (Table2,4). At day five, nitrification oxygen demand were between 0 and 1.0 mg/g with an average value of 0.3 mg/g. Five-day nitrification oxygen demand of the sediments accounted for 1.0% of combined oxygen demand by average. At day 10, nitrification oxygen demand of the sediment were between 2.0 and 4.8 mg/g and nitrification oxygen demand at day 20 were between 4.0 and 8.6 mg/g (Table 2). Average 10-day nitrification oxygen demand of the sediments were 3.1 mg/g which accounted for 14.2% of combined oxygen demand. Average 20-day nitrification oxygen demand of the sediments were 5.8 mg/g which accounted for 20.9% of combined oxygen demand. (Table2,3).

Five days combined oxygen demand of the sediments were between 11.0 and 35.4 mg/g then increased to 14.7 and 47.8 mg/g on day 10. Twenty days combined oxygen demand were between 17.7 and 55.1 mg/g(Table 3). Carbonaceous BOD increased rapidly during the first 8-10 days and then leveled off while combined oxygen demand still rising as the result of nitrification processes (Fig. 1-5).

Table 1. Carbonaceous biochemical oxygen demand of shrimp pond sediments (mg/g dry weight)

Days	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Average
5	15.9 (71.0%)*	10.0 (64.9%)	35.4 (70.8%)	13.8 (84.7%)	40.8 (66.3%)	23.2 (70.1%)
10	19.2 (85.7%)	11.7 (76.0%)	45.1 (90.2%)	16.3 (100.0%)	55.2 (89.8%)	29.5 (89.1%)
20	19.6 (87.5%)	13.7 (89.0%)	46.5 (93.0%)	16.3 (100.0%)	59.3 (96.4%)	31.1 (94.0%)
Ultimate BOD	22.4	15.4	50.0	16.3	61.5	33.1
k value (per day)	0.11	0.09	0.11	0.15	0.09	0.11

Remark: * = percent of ultimate BOD exerted

Table2. Nitrification oxygen demand of shrimp pond sediments (mg/g dry weight)

Days	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Average
5	0	1.0	0	0.4	-	0.3
10	4.8	3.0	2.7	2.0	-	3.1
20	4.9	4.0	8.6	5.6	-	5.8

Table 3. Combined oxygen demand of shrimp pond sediments(mg/g dry weight)

Days	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Average
5	15.9	11.0	35.4	14.2	-	19.1
10	24.0	14.7	47.8	18.3	-	26.2
20	24.5	17.7	55.1	21.9	-	29.8

Table 4. Percentage of nitrification oxygen demand in combined oxygen demand of shrimp pond effluents(%).

Days	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Average
5	0	1.4	0	2.8	-	1.0
10	20.0	20.4	5.6	10.9	-	14.2
20	20.0	22.6	15.6	25.6	-	20.9

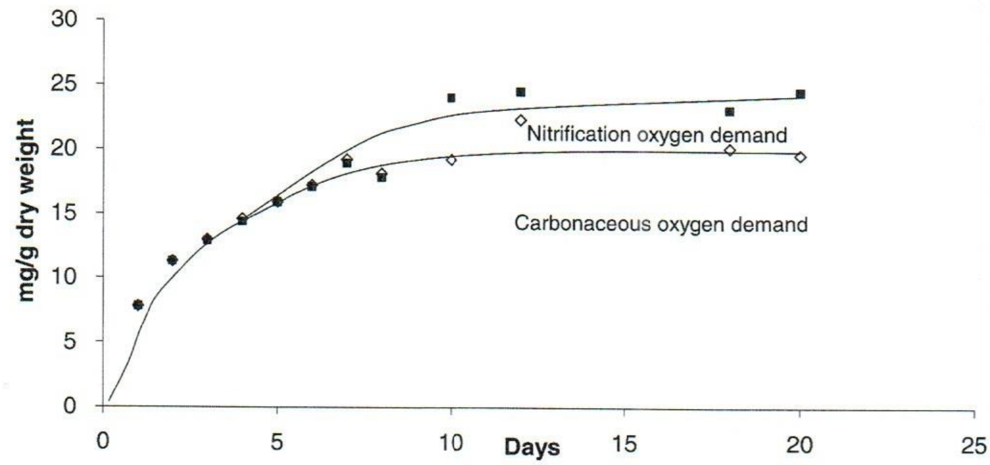

Fig. 1. Carbonaceous and nitrification oxygen demand of shrimp pond sediment in Koh Prerd, Laemsing district, Chantaburi province(Farm 1).

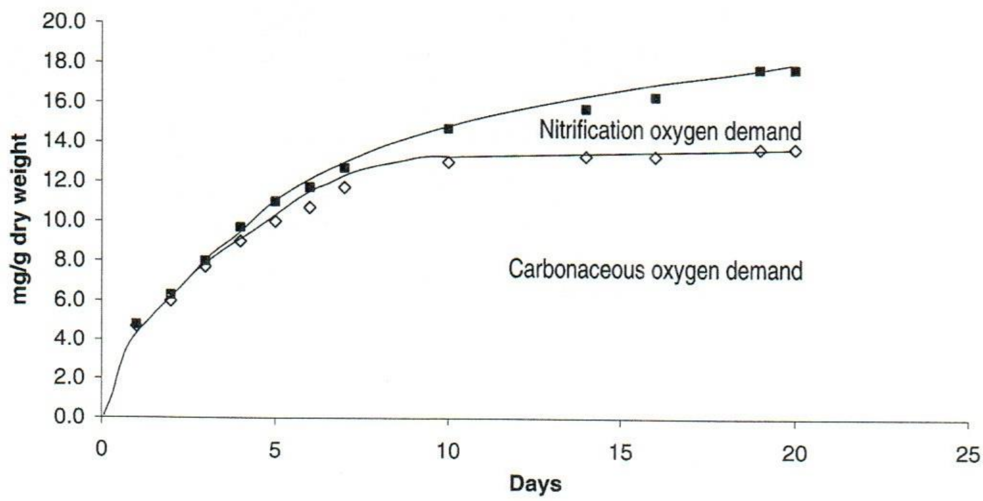

Fig. 2. Carbonaceous and nitrification oxygen demand of the sediment from shrimp farm in Tarng-Gwien, Klaeng district, Rayong province(Farm 2).

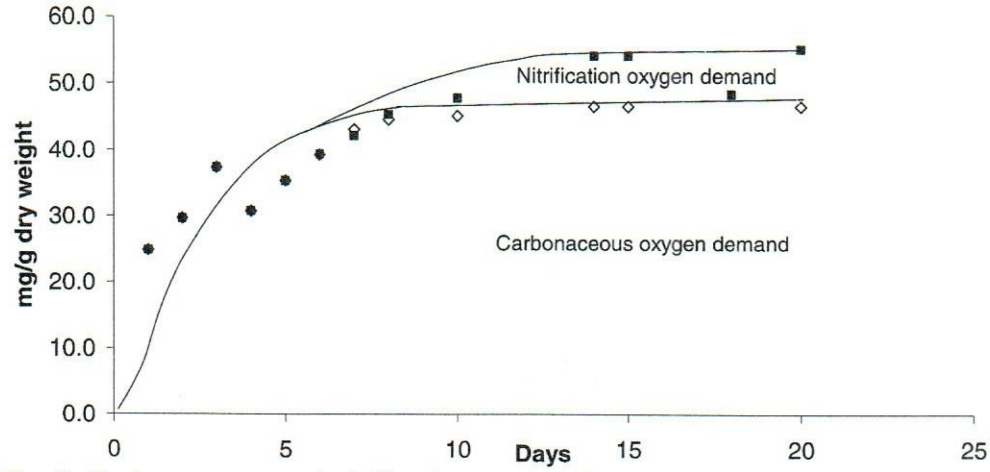

Fig. 3. Carbonaceous and nitrification oxygen demand of the sediment from shrimp farm in Pung-Lard, Klaeng district, Rayong province (Farm 3).

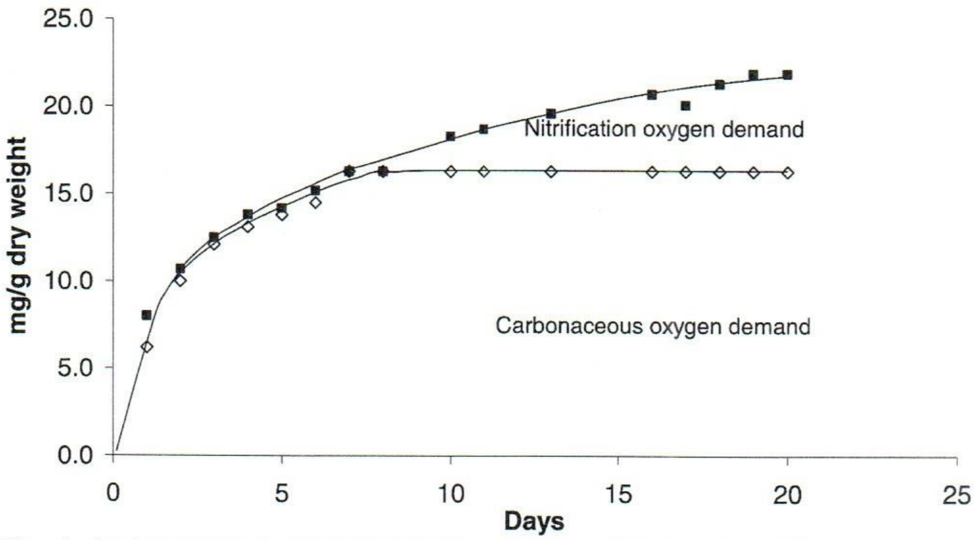

Fig. 4. Carbonaceous and nitrification oxygen demand of the effluent from shrimp pond in Tamai district, Chantaburi province (Farm 4).

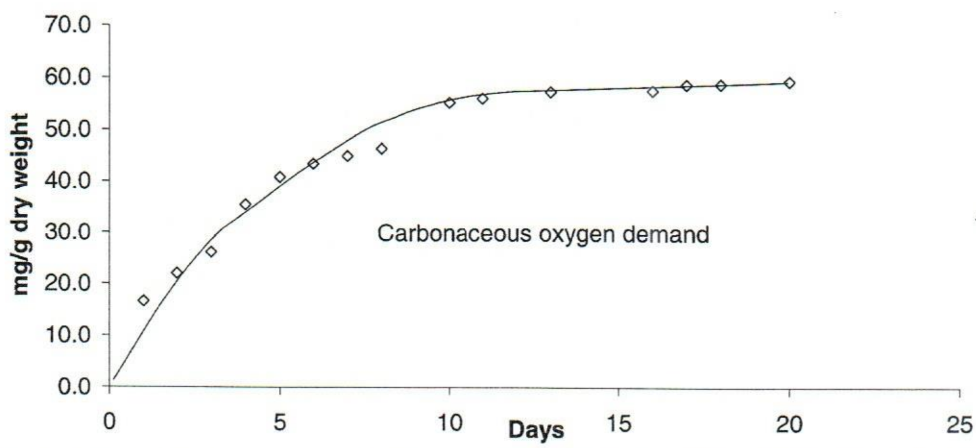

Fig. 5. Carbonaceous oxygen demand of the sediment from shrimp pond in Koh Prerd, Laemsing district, Chantaburi province (Farm 5).

Results of laboratory scale investigation indicated that aeration of overlying water and periodically stirring of the sediment can significantly increase reduction rate of BOD_5 of shrimp pond sediments. In the experiment with the sediment from farm 1, BOD_5 of shrimp pond decreased 6.6, 13.0, 13.0, and 15.2 percent at day 1, 3, 5, and 7, in control with no aeration and no stirring. In treatment with aeration and stirring, BOD_5 of the sediment decreased 6.6, 17.4, 34.8, and 43.6 percent at day 1, 3, 5, and 7.

In the experiment with the sediment from farm 2, BOD_5 of shrimp pond decreased 1.7, 1.7, 2.9, and 10.3 percent at day 1, 3, 5, and 7, in control with no aeration and no stirring. In treatment with aeration and stirring, BOD_5 of the sediment decreased 12.0, 24.1, 24.7, and 24.7 percent at day 1, 3, 5, and 7.

The decreasing rate of BOD_5 of shrimp pond sediments in treatment with aeration and stirring were significantly higher than the decreasing rate of control($P<0.5$) from day 5 for the sediment from farm 1 and from day 3 for the sediment from farm 2. Average decreasing rate of BOD_5 of the sediment in control and in treatment units with aeration and stirring were 4.1 and 9.3 percent on day 1, 7.3 and 20.7 percent on day 3, 7.9 and 29.7 percent on day 5, and 12.7 and 34.1 percent on day 7 (Table 5,6, Fig.6,7).

Table 5. Comparison of the change in BOD_5 of shrimp pond sediments in control(covered with water without aeration and without stirring) and in treatment(water was aerated and sediments were stirred daily)(average values: mg/g dry weight).

Farm 1			Farm 2	
Days	Control	Treatment	Control	Treatment
0	40.8	40.8	17.4	17.4
1	38.1	38.1	17.1	15.3
3	35.5	33.7	17.1	13.2
5	35.5	26.6	16.9	13.1
7	34.6	23.0	15.6	13.1

Table 6. The decreasing rates of BOD_5 of shrimp pond effluents with and without water aeration and sediment stirring(%).

Farm 1			Farm 2		Average	
Days	Control	Treatment	Control	Treatment	Control	Treatment
1	6.6	6.6	1.7	12.0	4.1	9.3
3	13.0	17.4	1.7	24.1	7.3	20.7
5	13.0	34.8	2.9	24.7	7.9	29.7
7	15.2	43.6	10.3	24.7	12.7	34.1

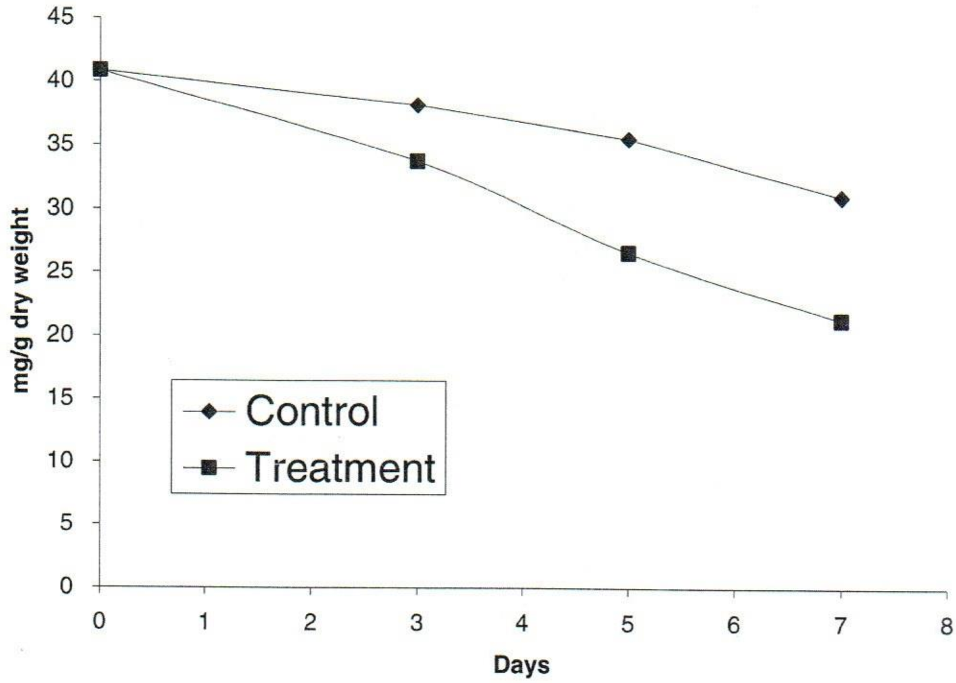

Fig. 6. Effect of water aeration and sediment stirring on BOD_5 of shrimp pond sediment from farm 1.

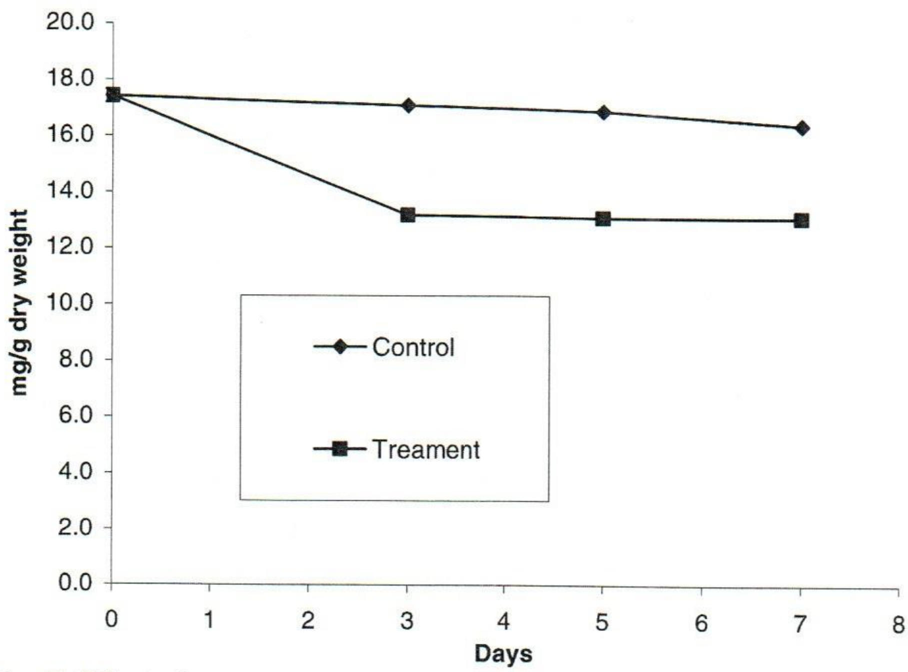

Fig. 7. Effect of water aeration and sediment stirring on BOD_5 of shrimp pond sediment from farm 2.

Discussion

The different among carbonaceous BOD_5 of the sediments from shrimp farms which varied between 10.0 and 40.8 mg/g dry weight may result from several factors such as culturing system, stocking density, feed and feeding, pond management, and pond age. Total or combined oxygen demand of the sediment at day 5 varied between 15.4 and 61.5 mg/g dry weight. At day 5, no nitrification oxygen demand was detected in two shrimp pond sediments but in the other two shrimp pond sediments nitrification oxygen demand were detected at low levels of 0.4 and 1.0 mg/g or about 1.4-2.8 percent of combined oxygen demand (Table2,3,4). According to Sawyer et al(1994), the nitrifying bacteria, which oxidize noncarbonaceous matter for energy, are usually present in relative small numbers, and their reproductive rate at 20°C is such that the populations do not become sufficiently large to exert an appreciable demand of oxygen until about 8 to 10 days have elapsed in the regular BOD test. Significant level of nitrification oxygen demand of the sediments in this study were detected starting from day 8 and day 10. Musig, et al (2003) reported similar result of the study on oxygen demand of shrimp pond effluents which low levels of nitrification oxygen demand were detected in some effluents at day 5 and significant level of nitrification oxygen demand of the sediments in were detected starting from day 7 and day 10.

High value of nitrification oxygen demand, which were between 15.6 and 25.6 percent and 5.6 and 20.4 percent of 20-day and 10-day combined oxygen demand, indicated that ammonia was accumulated in the sediment. The accumulation of large amount of ammonia in shrimp ponds resulting from the decomposition of uneaten and undigested shrimp which is high in protein content.

The average rate of biochemical oxidation (k) of 0.11 per day is very close to the average k value of 0.12 of shrimp pond effluents but lower than average k value of domestic waste which is about 0.17 per day. The k values of shrimp pond sediments varied from pond to pond in the range of 0.09 and 0.15 per day which is narrower than the range of the variation of k values of shrimp pond effluents which is varied from 0.06 to 0.18 per day(Musig et al , 2003). The k values for domestic waste also varied considerably from day to day and the k values for effluents from biological waste treatment plants were found to be significantly lower than that of the raw wastes (Hammer and Hammer, 1996; Sawyer, et al, 1994).

The nature of organic matter and the ability of the organisms present to utilize the organic matter are two major factors involving in the variation in k values. Organic matter which exists in true solution is readily available, but that part which occurs in colloidal and coarse suspension must await hydrolytic action before it can diffuse into the bacterial cells where oxidation can occur. The rate of hydrolysis and diffusion are probably the most important factors in controlling the rate of the reaction. Simple substrates, such as glucose, are removed from solution at very rapid rates, and k value are correspondingly high. More complex materials are removed much more slowly, and k values are lower. (Sawyer, et al, 1994).

Results from laboratory scale experiment with shrimp pond sediments indicated that aeration of overlying water and periodically stirring of the sediment increased the decomposition rate of organic matter in the sediment. Instead of drying or removing the sediment, some shrimp farmers in Thailand manage the sediment by plowing and harrowing pond bottom, while still keeping some amount of water in the pond, and left it for a period of time before filling it with water and restock the pond with shrimp larva. The aeration of overlying water and periodically plowing and harrowing of the sediment might improve sediment condition and increase the decomposition rate of organic matter in the sediment. However, more study is needed to investigate into more detail about the efficiency of this sediment management method.

Conclusion

Five-days carbonaceous biochemical oxygen demand ($CBOD_5$) of shrimp pond sediments varied between 10.0 and 40.8 mg/g dry weight with average value of 23.2 mg/g. BOD_5 values of the sediments were 64.9-84.7 percent of ultimate carbonaceous BOD. At day 5 only 2 of the 4 shrimp pond sediments exerted nitrification oxygen demand at low level of 0.4 and 1.0 mg/l. Ultimate carbonaceous BOD varied between 15.4 and 61.5 mg/g with average value of 33.1 mg/g. Average rate of biochemical oxidation (k value) of shrimp pond sediments was 0.11. The k values varied between 0.09 and 0.15 per day. Twenty-day nitrification oxygen demand varied between 4.0 and 8.6 mg/g with average value of 5.8 mg/g. Results of laboratory scale investigation indicated that aeration can significantly increase reduction rate of BOD_5 of shrimp pond sediment. High nitrification oxygen demand of the sediments indicated high accumulation of inorganic nitrogen, especially ammonia and nitrite, in the sediments.

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