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Comparative Study on Paddle-wheel Aerators Using Electric Motors and Diesel Engines in Pacific White Shrimp (*Litopenaeus vannamei*) Culture Ponds

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ABSTRACT

The purpose of the study was to compare water velocity, water quality, soil quality, production and energy costs of two paddle-wheel aerator systems, operated by electric motors and diesel engines, commonly used in shrimp farms. The study was separated into two experiments. The first experiment focused on water velocities produced by paddle wheel aerators using different rotational speeds. Research found that water velocity could not be measured at a distance of 25 meters away from the front of both systems' aerators at all the different speeds. The second experiment was performed in an intensive Pacific white shrimp farm. Three of the ponds were aerated using six long-armed paddle-wheel aerators, powered by two 11 hp diesel engines. The other three were aerated by six long-armed paddle-wheel aerators and used four 2 hp electric motors. Each paddle-wheel aerator was installed 25 meters apart. The results showed the ponds powered by the diesel engines obtained greater average production and higher average profit compared to the pond powered by the electric motors. This was because the paddle-wheel aerators using diesel engines could produce greater water velocity than the electric motors system. Consequently, they provided more dissolved oxygen to the water, cleaner feeding area, and removed the waste and sediment to the center of the pond more efficiently, which are important factors for the success of shrimp culture.

Key words: aerator, electric motor, diesel engine, Pacific white shrimp, shrimp culture

INTRODUCTION

Pacific white shrimp is commonly raised in South America and found in the Pacific Ocean from northern Mexico to the northern Peru. They were officially introduced to Thailand in 2002 and then their production increased significantly. However, during the same period, Black tiger prawn culture faced viral disease problems, and their numbers dropped more than 50% of the previous production. Since Pacific white shrimp were more prolific, they quickly became popular among the farmers (Limsuwan and Chanratchakool, 2004). A majority of the shrimp are cultured in closed systems to prevent waste and any causes of diseases from outside the farms. Although, culturing in these systems may cause water and soil quality problems as low water exchange, and releases toxic substances which may be direct or indirect effect on the shrimp.

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Thus, aeration is necessary for increased dissolved oxygen (DO) and improved pond bottom decomposition. Many studies also reveal that aeration improves water quality and increase yields in aquaculture ponds (Lai-fa and Boyd, 1988, Wyban *et al.*, 1989 and McGraw *et al.*, 2001). Circulation of pond water by aerators is an additional benefit of aeration for several reasons: (1) oxygenated water moves across the pond and shrimp can more readily find zones with adequate DO concentrations; (2) without constant movement of well-oxygenated water away from the aerator, aeration will increase DO concentrations in the vicinity of the aerator and greatly reduce oxygen-transfer efficiency; and (3) mixing of pond water by aerators reduces vertical stratification of temperature and chemical substances (Boyd, 1998). Boyd and Ahmad (1987) stated that the paddle-wheel aerators are more efficient at transferring oxygen and circulating water than other types of aerators. The paddle-wheel aerators are applied for these purposes, which not only increase the oxygen level in the ponds, but also keep the feeding areas clean and collect the sediment to the center of the pond. Aerators in shrimp farms powered by either electric motors or diesel engines have had very little research done, in terms of water velocity, sediment accumulation and production. Boyd (1997) recommended that each horsepower (hp) of aeration would support 500 kg of shrimp production. In Thailand, paddle-wheel aerators commonly implemented in shrimp farms are operated either by four 2 hp electric motors or two 11 hp engines. Therefore, the objectives of this study were to determine the effectiveness of paddle-wheel aerators with electric motors and diesel engines commonly employed by farmers in the intensive Pacific white shrimp culture ponds in regard to water velocity, sludge accumulation, energy cost and shrimp production.

MATERIALS AND METHODS

The study was performed at two locations, Samut Songkhram Fisheries Research Station and a commercial shrimp farm in Ratchaburi province, Thailand. These experiments were separated into two sections. The first section determined water velocities and the increased levels of dissolved oxygen levels created by two types of paddle-wheel aerators in a 0.16 ha pond at Samut Songkhram Fisheries Research Station. The first type was a 2 hp electric motor with one arm having four paddle-wheels and the second one was an 11 hp engine with one arm having eight paddle-wheels. The first type was able to operate at a single rotational speed of 110 rpm, while the second type could run at multi-speeds of 25, 35, 55, 70 and 90 rpm. The rotational speeds were measured at the shaft connected to the engine or motor using a Digital Photo Tachometer (Model DT-240P). In the experimental pond, 42 marking points were set up on a grid of 5 m wide and 5 m long in front of the paddle-wheel aerator (Figure 1).

The aerator was powered on for 30 minutes until dissolved oxygen level and water velocity was constant. Water velocity was determined with a flow meter (Model Global Water), which was rotated to find the maximum speed at each point. Dissolved oxygen level was measured with a polarographic probe DO meter (Cyberscan model DO100). Both water velocity and dissolved oxygen level were measured at all marking points, at three depths: 20, 60 and 80% from the water surface.

The second section was examined in a closed, low-salinity, commercial shrimp farm at Ratchaburi province for one crop (approximately four months). The results of water velocity in the first section were applied to the second section in terms of aerator placement. Six 0.48 ha cultured ponds were tested to compare two aeration systems commonly applied in shrimp farms. Three ponds used paddlewheel aerators operated by using four 2 hp electric motors (Figure 2a). The other three ponds were operated by using two 11 hp diesel engines as in Figure 2b. Water quality parameters were measured and collected at 2 m from the dike and 50 cm below the water surface at two opposite locations in the pond.

The water quality parameters: dissolved

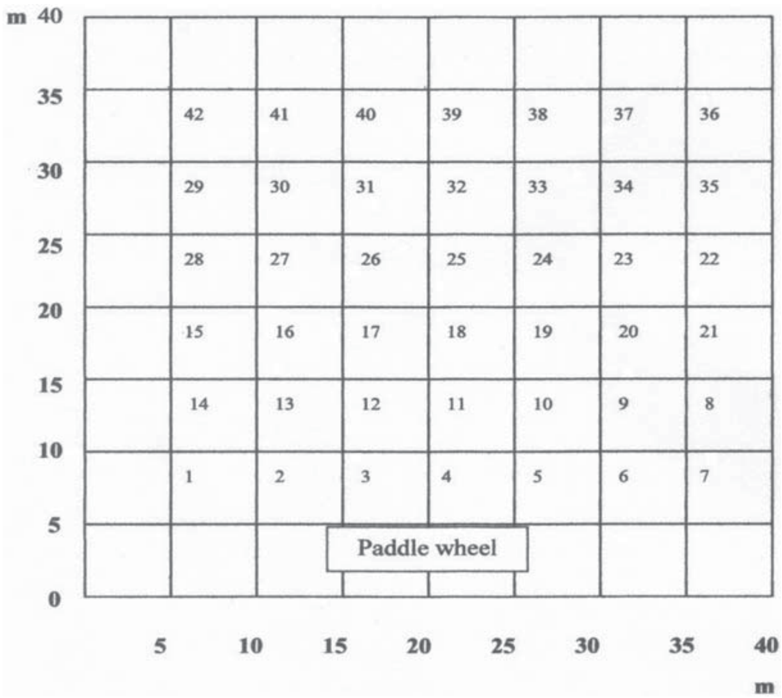

Figure 1 Shows 5×5 meter marking points in 0.16 ha experimental pond.

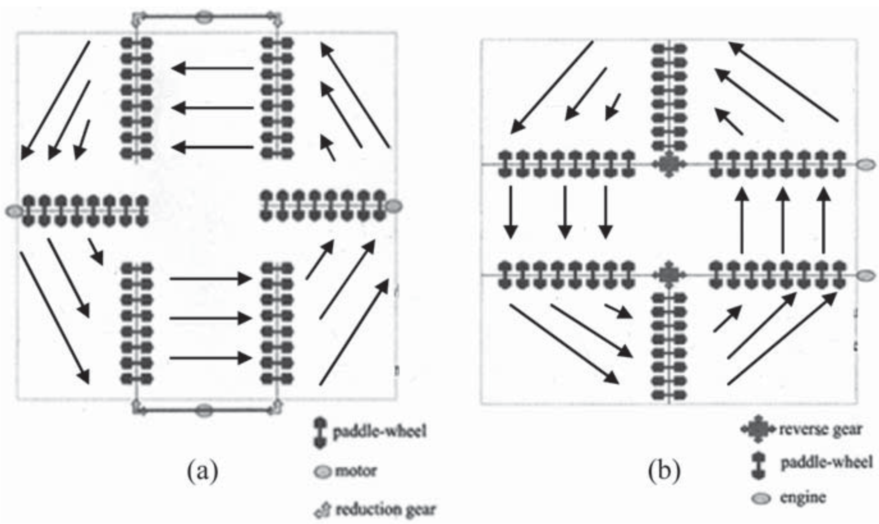

Figure 2 Shows the configuration of a 0.48 ha shrimp pond with paddle-wheel aerators (a) 2 hp electric motors (b) 11 hp diesel engines

oxygen, pH, temperature, salinity, total ammonia, nitrite-nitrogen, alkalinity, chlorophyll a were measured weekly. Dissolved oxygen was measured with a DO meter (Cyberscan model DO100). pH was measured with a pH meter (Cyberscan model pH500). Salinity was measured using a reflectosalino meter (ATAGO model S-10E). Total ammonia, nitrite-nitrogen, alkalinity and chlorophyll a were analyzed using a standard method (APHA *et al*., 1995). Soil samples at 5 cm depth were collected from two locations, in the center and in the feeding area of the pond. Soil quality, *e.g.* texture, organic matter and pH were measured monthly. Soil texture analysis was recorded using Kilmer and Alexander (1949) and Day (1965) methods using a Hydrometer. Organic matter was analyzed using the Walkley and Black method (Jackson, 1958). Soil pH measurement used a ratio of 1 : 1 (soil : water). The analysis was verified with a pH meter (Cyberscan model pH500). Water velocity was determined monthly at four locations of 10 m in front of each paddle-wheel aerator. At each location, water velocity was measured at three levels: 20, 60 and 80% under the water surface with a flow meter (Model Global Water).

After 30 days, shrimp growth rate were estimated weekly, using a cast net. At harvest, shrimp were weighted and calculated for survival rates, feed conversion ratio and total production. An amount of sediment in the center of the pond was roughly calculated using the formula of ¶.r^2 x average sediment depth (m). Where, r is a sediment radius (m). The economic data, *e.g.* the cost of feed, larvae, energy, labor, chemicals *etc*., was also calculated. The descriptive analysis such as means and standard deviations was employed for analysis of the data.

RESULTS AND DISCUSSION

Water velocity generated from paddle-wheel aerator with different rotational speeds

The water velocities decreased as the rotational speeds were lowered, at all distances (Figure 4a to f). The electric paddle-wheel aerator could only generate one speed of 110 rpm. The water velocities at 20, 60 and 80% under the water surface could be measured from the front of the aerator up to distances of 25, 20 and 15 m, respectively (Figure 5a). While, the paddle-wheel aerator using a diesel engine could generate different rotational speeds at 25, 35, 55, 70 and 90 rpm. As shown in Figure 5b to f, at 20% under water, water velocities could be measured at the distances of 15, 15, 20, 25 and 25 m using rotational speeds of 25, 35, 55, 70 and 90 rpm, respectively. At 60% under water, they could be measured at the distances of 10, 15, 15, 20 and 20 m with rotational speeds of 25, 35, 55, 70 and 90 rpm, respectively. At 80% under water, the distances were 5, 10, 10, 15 and 15 m with rotational speeds of 25, 35, 55, 70 and 90 rpm, respectively. These results showed that applying paddle-wheel aerator operated by either a 2 hp electric motor and an 11 hp diesel engine, at different rotational speeds, in a pond with a depth of 1 m could produce water movement no farther than 25 m from the front of the aerator. Therefore, aerators placement should not be made farther than 25 m from each other. This is similar to the recommendation of Limsuwan (2000), who suggested that suitable installation of aerators should not farther than 25-30 m from each other.

Water velocities, sediment accumulation, soil quality, water quality, cost and return of using two different paddle-wheels aerator systems

Soil textures in all experimental ponds were clay. As shown in Table 1, an average rotational speed in the ponds applying paddle-wheel aerators with electric motors during the culture period was 54.33±1.52 rpm. Averages water velocities at 20, 60 and 80% under water surface were 0.50±0.12, 0.21±0.02 and 0.10±0.01 m/s, respectively. The average sediment

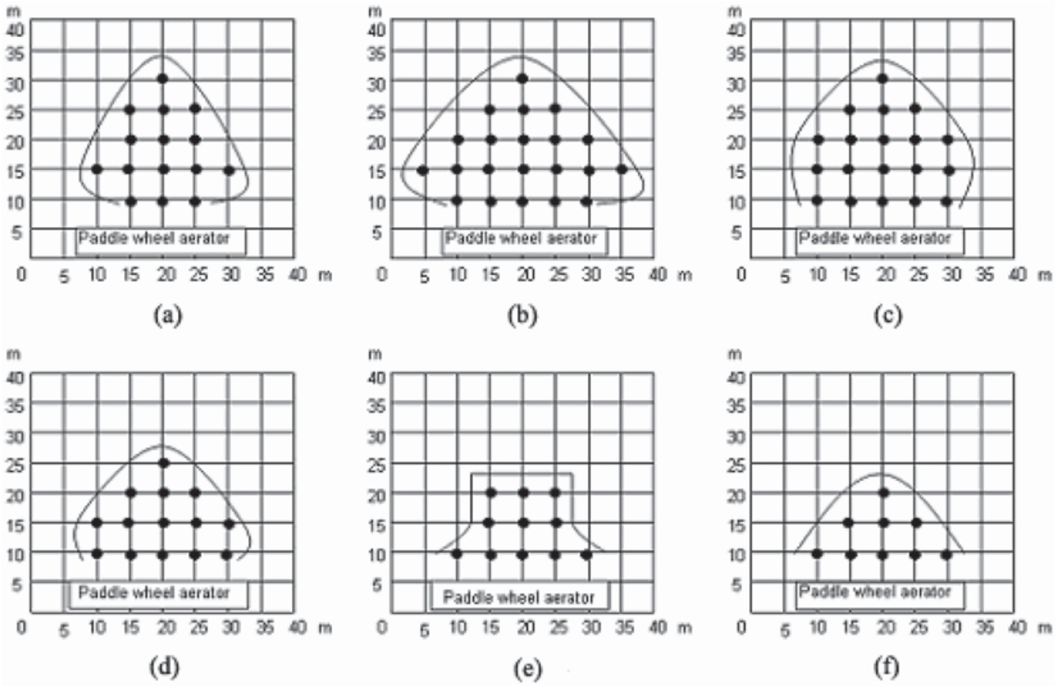

Figure 4 Pattern of water velocities (Top view) (a) at 110 rpm of a 2 hp electric motor, (b) at 90 rpm of an 11 hp diesel engine, (c) at 70 rpm of an 11 hp diesel engine, (d) at 55 rpm of an 11 hp diesel engine, (e) at 35 rpm of an 11 hp diesel engine, (f) at 25 rpm of an 11 hp diesel engine

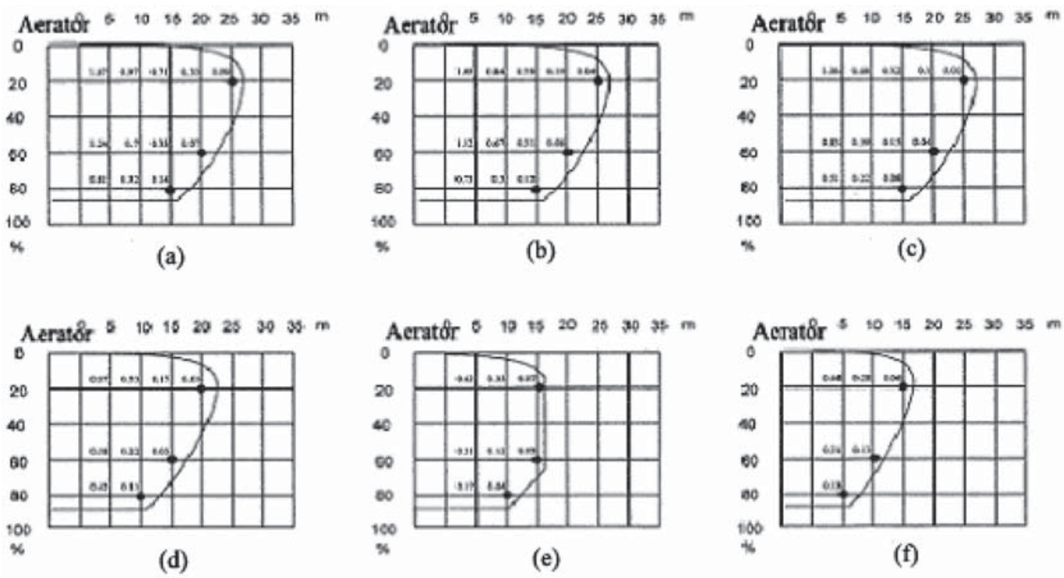

Figure 5 Pattern of water velocities (side view) (a) at 110 rpm of a 2 hp electric motor, (b) at 90 rpm of an 11 hp diesel engine, (c) at 70 rpm of an 11 hp diesel engine, (d) at 55 rpm of an 11 hp diesel engine, (e) at 35 rpm of an 11 hp diesel engine, (f) at 25 rpm of an 11 hp diesel engine

Table 1 Average (mean±SD) of rotational speed , water velocities at different water depth, sludge and soil quality.

Items	Paddle-wheel aeration system	
	Motors	Engines
Rotational speed (rpm)	54.33±1.52	70.58±0.38
Water velocity at 20% from water surface (m/sec)	0.50±0.12	0.67±0.00
Water velocity at 60% from water surface (m/sec)	0.21±0.02	0.38±0.01
Water velocity at 80% from water surface (m/sec)	0.10±0.01	0.21±0.00
Sludge at the center of the pond (m^3/ha)	94.25±2.25	99.88±1.94
Organic matter at the center of the pond (%)	2.24±0.12	1.91±0.04
Organic matter at the feeding area (%)	0.55±0.03	0.44±0.04
Soil pH	7.22±0.12	7.28±0.02

accumulated in the center of the pond was 94.25±2.25 m^3/ha. Sediment quality parameters, *e.g.*, organic matter and pH were 1.91±0.04% and 7.22±0.12, respectively. While, average rotational speed of the ponds applying paddle wheel aerators using diesel engines was 70.58±0.38 rpm, average water velocities at 20, 60 and 80% under water surface were 0.67±0.00, 0.38±0.01 and 0.21±0.00 m/s, respectively. Average sediment in the center of the ponds was 99.88±1.94 m^3/ha. Organic matter and pH of the sediment were 2.24±0.12% and 7.28±0.02, respectively.

The electric driven paddle-wheels had a lower average rotational speed and a less effective range than the diesel driven paddle-wheels at all depths. This resulted in greater accumulation of organic matter at the center and at the feeding area of the ponds than using the diesel engines. Accordingly, using diesel engines could accumulate the sediment at the center of the ponds more effectively than using the electric motors.

The average water velocities at 80% under water surface of ponds using diesel engines and electric motors were 0.21 m/s and 0.10 m/s, respectively. There seemed to be bottom erosion in the ponds, as the water velocities were faster than 0.076 m/s according to recommendation by Roger (1990). Roger (1990) noted that a minimum of water velocity of 0.05 m/s would prevent water stratification, whereas 0.15 m/s was required for sediment suspension, thus the water velocity of 0.076 m/s was suitable for destratification and sediment removal, without disturbing pond bottom.

Of the ponds applying paddle-wheel aerators using electric motors, averages of dissolved oxygen at 20, 60 and 80% under water surface were 9.34±0.24, 6.92±0.14 and 4.26±0.17 mg/l, respectively. Other water quality parameters, *e.g.*, pH in the morning, pH in the afternoon, alkalinity, nitrite-nitrogen, total ammonia and chlorophyll a were 7.78±0.06, 8.11±0.04, 84.53±1.48 mg/l, 0.085±0.000 mg/l, 0.024±0.000 mg/l and 7.85±1.57 mg/m^3, respectively (Table 2). Whereas, the ponds applying paddle wheel aerators using diesel engines, averages of dissolved oxygen at 20, 60 and 80% under water surface were 9.85±0.12, 7.02±0.06 and 4.65±0.10 mg/l, respectively. Other water quality parameters, *e.g.*, pH in the morning, pH in the afternoon, alkalinity, nitrite-nitrogen, total ammonia and chlorophyll a were 7.90±0.04, 8.20±0.05, 83.29±1.46 mg/l, 0.098±0.000 mg/l, 0.021±0.000 mg/l and 10.70±1.87 mg/m^3, respectively (Table 2).

All water quality parameters were in an acceptable level for shrimp growth, as dissolved oxygen not lower than 3 mg/l, pH between 7.5-8.5, total ammonia not more than 1.0 mg/l and nitrite-nitrogen not more than 0.1 mg/l (Boyd and Fast, 1992; Lawson, 1995, Limsuwan and

Table 2 Average (mean±SD) of water quality parameters in the ponds using paddle-wheel aerators operated by electric motors and diesel engines.

Water quality parameters	Paddle-wheel aeration system	
	Motors	Engines
DO at 20% from water surface (mg/l)	9.34±0.24	9.85±0.12
DO at 60% from water surface (mg/l)	6.92±0.14	7.20±0.06
DO at 80% from water surface (mg/l)	4.26±0.17	4.65±0.11
pH morning	7.78±0.06	7.95±0.04
pH afternoon	8.11±0.04	8.23±0.05
Alkalinity (mg/l)	84.50±1.48	83.29±1.46
Nitrite-nitrogen (mg/l)	0.085±0.000	0.098±0.000
Total ammonia (mg/l)	0.024±0.000	0.021±0.000
Chlorophyll a (mg/m^3)	7.85±1.57	10.7±1.87
Temperature (C°)	29.34±0.05	29.26±0.09
Salinity (ppt)	3.98±0.03	4.02±0.03

Chanratchakool, 2004).

Due to greater water velocities in the ponds using diesel engines, dissolved oxygen at all levels were higher, average chlorophyll a content was superior and total ammonia level was lower compared to using electric motors. These were because greater turbulence made better water surface to air exchange and mixed nutrients for phytoplankton growth.

The results showed that average survival rates and FCRs of the ponds using electric motors for running aerators were 70.12±0.38 % and 1.44±0.00 which were higher than of those using diesel engines at 68.04±1.10 % and 1.42±0.00, respectively. While the ponds using diesel engines obtained higher average production level at 7,010±25 kg/ha, greater production cost at 15,095±55 USD/ha and more profit at 7,647±35 USD/ha than the ponds using electric motors at 6,477±20 kg/ha, 14,123±50 USD/ha and 6,028±13 USD/ha, respectively (Table 3). These were for to two main reasons, *i.e.*, (1) the ponds using diesel motors had lower average survival rate, thus the shrimp could grow faster and finally gained greater production and higher profit although they spent higher energy cost, (2) running paddle wheel aerators using diesel engines created greater water velocities in the ponds than those using motors.

Table 3 Average (mean±SD) of survival rate, FCR, production, production cost, profit and energy cost in the ponds applied paddle wheel aerators using motors and engines.

Items	Paddle-wheel aeration system	
	Motors	Engines
Survival rate (%)	70.12±0.38	68.04±1.10
FCR	1.44±0.00	1.42±0.00
Production (kg/ha)	6,477±20	7,010±25
Production cost (USD[1]/ha)	14,123±50	15,095±55
Profit (USD/ha)	6,028±13	7,647±35
Energy cost[2] (USD/ha)	1,968±0	2,431±0

[1] 1 USD = 36 Baht

[2] Based on the calculation of electric price at 0.08 USD/unit and diesel price at 0.72 USD/liter

Thus, they could be better providing dissolved oxygen to the water, mixing water, cleaning feeding area, and removing the waste and sediment to the center of the pond which are important factors of success in shrimp culture. Clean areas are preferred to the shrimp as shrimp which normally live on or near the bottom, are exposed to conditions on pond bottom (Avnimelech and Ritvo, 2003). These are supported by the study of Delgado *et al* (2002) who found that shrimp abundance was significantly lower in the center region because its condition may have been less favorable for shrimp growth and health.

CONCLUSION

The aerators should not be positioned more than 25 m. from each other. Although using diesel engines seemed more profitable than those using electric motors, there was not much difference. Therefore, the shrimp farmers have to consider which one is suitable for their own farms. The advantages of using electric motors are longer life, less noise, more reliable, easier to operate and lower maintenance costs. Of course, it is only suitable for use where electricity is available. While the advantages of diesel engines are lower initial cost and variable rotational speed. Another important factor is the energy cost at that time. Furthermore, a high rate of aeration may cause excessive water current which could badly erode the pond bottom and embankment. The results of the study found that each horsepower of aeration using diesel engine and electric motor produced 50 kg and 130 kg of shrimp production respectively. These were lower than Boyd's recommendation, where each horsepower of aeration would support 500 kg of shrimp production. Further study should focus on determining suitable water velocities as recommended by researchers in cultured pond, in terms of erosion, cleaning feeding area, accumulating sediment in the center of the pond, production, energy costs and profit.

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