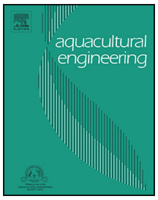
Aquacultural Engineering 74 (2016) 62–69

Contents lists available at ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aqua-online



Development and performance evaluation of sludge remover for intensive aquaculture

M. Ayub Hossain[a,*], Ashoke Kumar Sarker[b], M. Nurul Amin[a], M. Mokarrom Hossain[a], M. Sumon Miah[a]

[a] *Farm Machinery and Postharvest Process Engineering (FMPE) Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh*
[b] *WorldFish, Bangladesh and South Asia, Banani, Dhaka, Bangladesh*

ARTICLE INFO

Article history:
Received 14 February 2016
Received in revised form 2 June 2016
Accepted 3 June 2016
Available online 5 June 2016

Keywords:
Fish pond
Sludge remover
Water quality
FCR
SGR
Net return

ABSTRACT

Fishery is an emerging sector in Bangladesh producing about 3.50 million tons of fish annually of which aquaculture accounts for 2.00 million tons. In intensive aquaculture, pond water gets polluted due to high stocking density and large amount of supplemental feeding results in huge accumulation of unused feed and faeces in the pond bottom. The accumulated bottom sludge depletes dissolved oxygen (DO) and releases harmful gases due to excessive use of chemicals and lack of water exchange facilities. These have negative impact on fish production and economic performance, through disease outbreak, mortality, poor feed conversion ratio (FCR), specific growth rate (SGR) and bad odor in fish muscles. This study was undertaken to develop a sludge remover for cleaning sludge from the intensive fish farming pond and to find the impact of sludge removal on water quality and growth of fish. A sludge remover was developed in Bangladesh Agricultural Research Institute (BARI) which is capable of removing sludge up to 40–50 mm from the pond bottom. The main components of sludge remover are a float, axial flow pump (102 mm diameter), 7.50 kW diesel engine, sludge sucker, crane, propeller, rudder, etc. The discharge of the sludge pump was 14.11 L/s. The effective field capacity and field efficiency were 0.078 ha/h and 77.23% respectively at the forward speed of 12.5 ± 1.55 m/min. The water and sludge ratio was 3.6:1.0 (weight basis). A field trial was carried out to determine the effect of sludge removal on water quality and growth of fishes in intensive cultured ponds. Sludge was removed at three months interval from three pangus-tilapia-carp polyculture ponds. Three ponds of same size and fish stocking were kept as control. Water quality parameters like DO, pH, transparency and, unionized ammonia significantly ($p \leq 0.05$) improved in the sludge removed ponds compare to control ponds. Sludge removed ponds demonstrated better FCR (1.64) and SGR (0.80% per day) compare to FCR (1.90) and SGR (0.71% per day) of control ponds. Fish survival, net yield, net return and BCR (5.40) of sludge removed ponds were higher than those of control ponds. This sludge remover may be recommended for cleaning sludge from intensive cultured fish ponds.

1. Introduction

The fisheries sector is the second largest part-time and full-time employer in rural areas, directly engaging over 60% of the rural population in Bangladesh (DoF, 2014). Fish production in Bangladesh has increased by 53% from 2004 to 2014 (FAO, 2014). Pond culture represents the mainstay of aquaculture in the country, accounting for 85.8% of total production and 57.7% of the area under culture. Fish catch from ponds and ditches now accounts for 41% of total yearly production (DoF, 2014). Belton et al. (2011) reported that 4.27 million households (20% of rural inhabitants) operate a homestead pond, covering a combined area of 265,000 ha. Commercial semi-intensive carp culture covers an area of 110,000 ha, and intensive forms of entrepreneurial pond culture cover 15,000 ha. An estimate derived from this source states that around 399,000 t of fish are produced from homestead ponds; 390,000 t from commercial semi-intensive carp culture; 395,000 t from pellet fed intensive systems; and 98,000 t of shrimp and prawn. So, these fishes are now considered the main source of animal protein (57%) in Bangladesh. In fact, in a country like Bangladesh where fish culture has a long tradition, pond fish culture plays an important role in supplying increasing fish needs of the people (Chowdhury and Maharjan, 2000). It is very important to increase the production in pond fisheries with controlled water bodies through the introduction of

---

* Corresponding author.
E-mail address: mahossain.fmpe@gmail.com (M.A. Hossain).

http://dx.doi.org/10.1016/j.aquaeng.2016.06.001
0144-8609/© 2016 Elsevier B.V. All rights reserved.

modern and intensive culture method. Hence, pond fish culture has become a major income-generating enterprise in rural development programmes and supplemented with crop production and animal husbandry. This may improve livelihood of the rural poor in Bangladesh.

There are two kinds of technical constraints to pond fish production: abiotic (e.g., problems with water, soil, temperature, etc.) and biotic (e.g., pests, predators and disease). Dey et al. (2005) estimated the annual financial loss caused by the various biotic and abiotic factors is about US$ 243/ha. One of the main abiotic problems is deposition of aquaculture sludge in pond bottom. Aquaculture sludge is composed of fish faeces and uneaten fish feed that settle down at the bottom of the pond (Birch et al., 2010). It is reported that sludge from fish farms originates from three origins: fish faeces, drum filters and biofilters. Dewatering and managing the sludge is a challenging task, as it is very unstable. It is also reported that an average to large land-based fish farm (1000 t feed/year) can produce up to 15 t of dry sludge each month equivalent to 150 m^3 wet sludge with approximately 200 g of suspended solids (SS) per kilogram of fish feed (DHI, 2015). This sludge needs to be managed and discarded properly for desirable growth of fish. Anh et al. (2010) analyzed water pollution caused by farming and processing pangasius in the Mekong Delta of Vietnam. They reported that one ton of frozen fillets released 740 kg Biological Oxygen Demand (BOD), 1020 kg Chemical Oxygen Demand (COD), 2050 kg TSS (total soluble solids), 106 kg nitrogen and 27 kg phosphorus. Chen et al. (2007) reported that waste discharge from recirculating aquacultural systems is typically in the form of sludge composed of partially stabilized excreta, uneaten food particles, and bacterial growth. The production of TSS ranges from 10 to 30% of the feeding rate on a dry weight basis. The ratio of 5-d (diluted solution after 5 days incubation) biochemical oxygen demand to total suspended solids (BOD_S/TSS) of the sludge ranges from 0.10 to 0.20. Haque et al. (2016) reported that average organic carbon, total nitrogen, available phosphorus, potassium and sulfur contents of pangasius pond sediments (sludge) in Mymensingh, Bangladesh are reported as 3.15%, 0.30%, 115.60 $mg\,kg^{-1}$, 106.80 $mg\,kg^{-1}$ and 86.06 $mg\,kg^{-1}$, respectively.

Abdelhamid et al. (2014) reported that regardless of fish species, feeding fish in sewage sludge led to significantly lower values of growth performance compared to those fed in the clean water. Much contamination could be occurred in humans by consuming fish reared under polluted water conditions or fish fed contaminated diets (Abdelhamid et al., 1996, 1999). Davidson and Summerfelt (2005) reported that accumulation of solids within aquaculture tanks and systems can promote an environment that harbors fish pathogens. In addition, solids that are not rapidly removed can break down into smaller particles that leach nutrients, degrade water quality, and exert a biological oxygen demand that also increases dissolved carbon dioxide level. The smaller suspended solids can cause gill irritation, which can lead to reduce immune system efficiency, and ultimately cause disease outbreak. Rapid and effective solid removal can positively affect the health of salmonid species in water recirculating systems (Bullock et al., 1997). So, a sludge removal system needs to be developed for easy and efficient removal of sludge from fish pond.

Cereal Systems Initiative for South Asia-Bangladesh (CSISA-BD) in 2011, conducted a series of Focal group discussion (FGD) in Jessore region of Bangladesh to identify the problems of commercial and intensive aquaculture. These FGDs revealed that commercial aquaculture depended on commercial pelleted feed, uneaten feedstuffs and faeces of the fish. These have been identified as major contributors to sludge generation and deposition in commercialized Thai pangus-tilapia-carp farming (CSISA-BD, 2011). As a result, harmful gases are produced from the decomposition that cause oxygen depletion in water and create bloom, affecting productivity of the system. This might be the reason of huge mortality of fish in the intensive farms throughout the season. They are forced to apply drug and chemicals indiscriminately to minimize fish mortality which eventually lead to economic loss of the commercial farms. It is reported that farmers use chemicals amounting US$ 564/ha/year to reduce mortality of fish. Due to mortality of fish (2.0–4.5 t/ha/year), farmers loose about US$ 5128/ha/year (Total production 27.0 t/ha). The fishes are fed twice or thrice daily with a commercial pelleted feed that contains 24–28% crude protein but no water exchange facilities is available in ponds except for adding some underground water. From the beginning of a production cycle, fish mass needs sufficient dissolved oxygen (DO) for better metabolism to convert given feed efficiently but DO in those pond water found lower than optimum level.

A number of physical, chemical and biological methods used in conventional wastewater treatment has been applied in aquaculture systems. These methods are suitable for tank or small ponds. For large and commercial intensive aquaculture, these systems are inadequate (Turcios and Papenbrock, 2014). So, mechanical method of sludge removal may be the solution for commercial intensive aquaculture. In Vietnam, farmers are using sludge pump for removing sludge from fish pond to create healthy environment in the fish pond (Boyd et al., 2011). Sludge pumps are generally used at the bottom of fish ponds to suck out wastes, sunken debris and other contaminants. The pumps are attached to a discharge tube and a power source. But there is no sludge pump readily available in Bangladesh. Therefore, this study was undertaken to develop a sludge remover and to evaluate the performance of the sludge remover for intensive aquaculture.

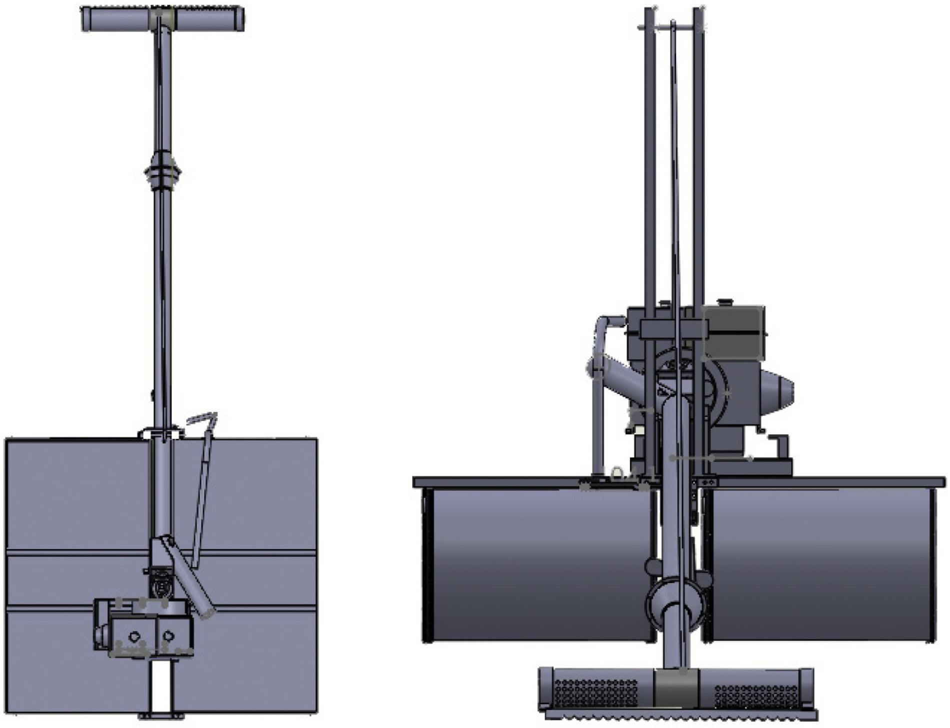
2. Materials and methods

2.1. Design of the sludge remover

A sludge remover was designed and fabricated at Farm Machinery and Postharvest Process Engineering (FMPE) Division of Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh with locally available materials. The main functional components of the remover were axial flow pump, engine, suction pipe, sludge collector with cutter, delivery pipe, float, propeller, rudder, crane, etc. Engineering drawing was made using Solid Works-14 software showing different spare parts with scale. The plan and back views isometric view of sludge remover are shown in Fig. 1. Also the isometric view of sludge remover is shown in Fig. 2.

2.2. Description of sludge remover

Axial flow pump of 102 mm diameter was used for suction of the sludge from the bottom of fish pond. It is one of the essential parts of the sludge remover that collects the sludge from the bottom of the pond through suction mode. For avoiding priming, and to get higher discharge at low head (≤4.0 m), axial flow pump was used. The components of the pump were metal pipe (102 mm diameter and 3.0 m long), solid shaft (12.5 mm diameter), impeller with 5 blades, (165 mm diameter), pulley (76 mm), flexible plastic pipe (102 mm diameter), bearing, bush etc. A single cylinder 7.5 kW diesel engine (R190N, Changchai, China) was used as prime mover. This engine is available in the local market. The power from engine to pump was transmitted by direct coupling and to propeller by pulley and V-belt. Sludge collector was made of perforated plastic pipe. The pipe was 165 mm diameter and 1.44 m long. The one fourth diameter of the plastic pipe was perforated with 20 mm diameter holes. A cutter of 1.35 m long and 102 mm width, made of MS (mild steel) sheet was fixed at the bottom of the hollow pipe. Float is an



(a) Plan

(b) back view

Fig. 1. Plan and backview of sludge remover (scale: 1:20). (a) Plan, (b) back view.

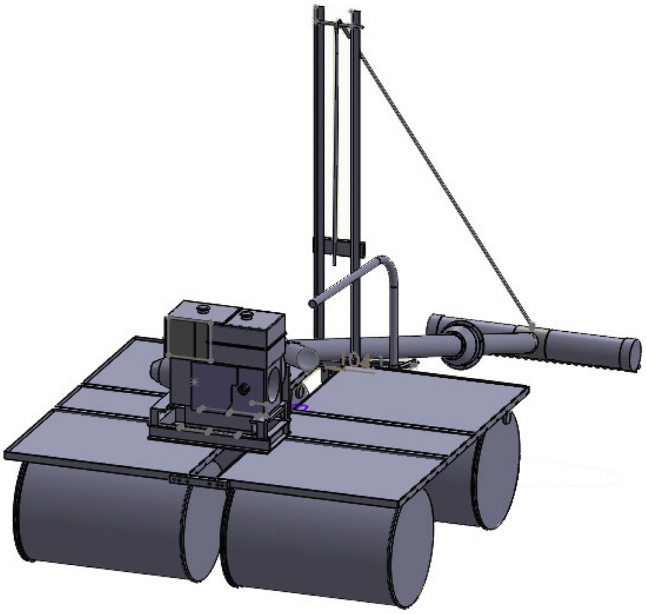


Fig. 2. Isometric views of sludge remover (scale: 1:20).

essential component of the sludge remover to float and carry the prime mover, sludge pump, crane, rudder, operator, suction pipe, etc. The size of the float was 1.20 m × 0.90 m. It was made of four metal drums (used), MS angle bar, MS sheet, MS flat bar, wooden platform, etc. It was made so that it can carry the weight of engine pump, crane and three persons and also had quick dismantling and assembling facility for easy transportation from one place another. The photographic view of the sludge sucker is shown in Fig. 3.

Fig. 3. Photograph of sludge sucker attached with sludge pump.

2.3. *Operation principle*

The components of the sludge remover are carried on the dyke of the pond where sludge remover is to be operated. At first, float is placed in the pond water. Then pump, engine, crane, propeller, rudder, and delivery pipe are fitted with the float. Two operators are required to operate the sludge remover. One person operates the machine, riding on the float and another person manages the sludge pipe from the dyke of the pond. Sludge pump with sucker is adjusted according to the depth of water. Engine is started and the mixture of sludge and water comes out through delivery pipe to the sludge deposition pit or tank. Amount of sludge can be increased or decreased by lowering or lifting the sludge sucker by the lever of the crane. When the position of sludge sucker is adjusted then propeller is started by the lever. Then the float with sludge pump moves forward. The speed of float may be increased or decreased by adjusting the propeller lever. The direction of the movement is controlled by rudder. Sometimes it is difficult for turning of the sludge remover using existing rudder. Then the float is turned around with the help of a bamboo pole (usually used in boat). The position of the delivery pipe is adjusted by another operator. In this method, sludge from the bottom of the pond begins to get removed from one side of the pond and get finished up to another end. When the sludge deposition pit or tank is filled up another pit or tank is be used. This procedure is continued until the removal of sludge from the whole pond is completed.

The performance of the sludge remover was evaluated in terms of field capacity and field efficiency in the real field. The theoretical field capacity of a machine is the rate of field coverage that would be obtained if the machine performing its function 100% of the time at the rated forward speed and always cover 100% of its rated width. On the other hand, effective field capacity is the actual average rate of coverage by the machine. Field efficiency is the ratio of the effective field capacity to theoretical field capacity. Theoretical field capacity, effective field capacity and field efficiency of sludge remover were determined using following formula (Kepner et al., 1987).

$$\text{Theoretical field capacity, } C_{th} = \frac{WS}{10} \tag{1}$$

Where, C_{th} = theoretical field capacity (ha/h)
S = forward speed (km/h)
W = rated width of machine (m)

$$\text{Effective field capacity, } C_{ef} = \frac{A}{t} \tag{2}$$

Where, C_{ef} = effective field capacity (ha/h)
A = Area coverage (ha)
t = operating time (h)

$$\text{Field efficiency, } e = \frac{C_{ef}}{C_{th}} \tag{3}$$

2.4. Field experiments

Field experiments were carried out in six farmers' ponds at Goalbari village under Monirampur Upazila (Sub-district) of Jessore district (23°10′07″N latitude, 89°12′47″E longitude), Bangladesh for a period of about 10 months from May 2014 to March 2015. Two treatments with three replicates were considered in this field experiment. One treatment (T_1) was sludge cleaned from pond bottom with sludge remover and another treatment (T_2) was pond bottom not cleaned (Control) during the fish grow-out period. The water area of each pond was 0.13–0.15 ha. The fish fingerlings were stocked in 9–10 May 2014 at the rate of 47,887–47,946 number ha^{-1} in all the experimental ponds. Polyculture system was adopted with three commercially important fish species pangus (*Pangasius hypophthalmus*) tilapia (*Oreochromis niloticus*) and major carps at the ratio 60%, 20% and 20% respectively such as silver carp (*Hypopthalmichthyes molitrix*), rohu (*Labeo rohita*), catla (*Catla catla*), mrigal (*Cirrhinus cirrhosus*) and grass carp (*Ctenopharyngodon idella*). Fish were fed twice daily with the same commercial pelleted feed (*Teer*-local feed brand) and at the rate of 5–10% of the total fish biomass in both T_1 and T_2 ponds. Feeds were applied in the fish ponds at 9:00 am and 3:00 pm hours daily. Sludge from the bottom of the experimental ponds (T_1) was removed by the developed sludge remover at two months interval after three months of stocking of fishes. Sludge remover was used to clean the sludge from the bottom of each T_1 ponds (0.13–0.15 ha) followed by one hour groundwater filling. Water quality parameters (Temperature, pH, dissolved oxygen, transparency and total ammonia) were recorded at 7:30 am and 4:00 pm in every week. Temperature of water was measured with a digital thermometer (Brand: Conrad Electronic, model: K102, capacity: 200 °C, readability: 0.1 °C, made in Germany) and water pH was measured with a pH meter (Brand: Hanna Instruments, model: HI 98107, capacity: −2.00 to +16.00, readability: 0.05, made in Romania). Water transparency was measured using locally made secchi disk. Dissolved oxygen (DO) of pond water was measured by DO meter (Brand: Lutron Electronic Enterprise, model: PDO519, readability: 0.4 mg/L, made in Taiwan). Total ammonia of pond water was determined by ammonia test kit (Brand: Hanna Instruments, model: HI 3824, readability: 0.4 mg/L, made in Romania) using the Nessler method (Zhou, 2015). Then un-ionized ammonia was calculated using the equation by Emerson et al. (1975).

Fish growth was monitored in each month by random sampling method. Fishes were caught by casting net and then were measured the weight and length of 20 individual fishes from each of the ponds. Weight of individual fish was recorded using a digital balance (Brand: Sartoroius, Model: CP3202S, capacity: 3200 g, readability: 0.01 g, made in Germany). Weights of fish samples were measured of all the experimental ponds in the same day. At the end of the experiment, the fishes were harvested by netting repeatedly with fine meshed seine net from each pond and then weighed and marketed. Average weight of pangus, tilapia, and carps on harvesting date were 1.08 ± 0.12, 0.35 ± 0.08 and 0.54 ± 0.17 kg, respectively. The selling prices of pangus, tilapia and carps per kilogram of biomass were of US$ 1.21 (BDT 95), US$ 1.14 (BDT 89) and US$ 1.26 (BDT 98), respectively. The harvesting dates were 29–30 March 2015. Growth parameters of fish were calculated as follows.

$$\text{Weightgain (g)} = \text{Final weight(g)} - \text{Initial weight (g)} \tag{4}$$

$$\text{Survival(\%)} = \frac{\text{Number of fish harvested}}{\text{Number of fish stocked}} \times 100 \tag{5}$$

Net yield (ton ha^{-1}) = Total biomass at harvest (ton) − Total biomass at stocking (ton)

Feed Conversion Ratio (FCR) was calculated as per Sayeed et al. (2008).

$$\text{FCR} = \frac{F}{M_f - M_i} \tag{6}$$

Where, F is total feed offered (Dry matter basis), M_f is total final body weight and M_i is total initial body weight.

Specific growth rate (SGR) of fish was calculated according to Watanabe et al. (2001) as follows.

$$\text{SGR(\%)} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1} \times 100 \tag{7}$$

Where, W_1 is mean stocking weight (g), W_2 is mean harvest weight (g) and t_1 and t_2 (days) are the stocking and harvesting days, respectively.

2.5. Economic analysis

Total cost was composed of fixed cost and variable cost. The capital cost was the sum of the price of sludge remover and rent of the ponds. Fixed cost was the sum of depreciation of sludge remover, interest on investment, repair and maintenance costs of machine and engine. Depreciation is often defined as the annual loss in value due to use, wear, tear, aging, and technical obsolescence. Several methods or equations can be used to compute annual depreciation. Straight line method was used in this study to calculate depreciation. The useful life of sludge remover and diesel engine operated pump were assumed to be 8 years. Annual interest rate was considered 14% of the capital price of the pump. Variable cost was the sum of labour, fuel, oil, feed, chemicals, fingerling and other management costs. Then gross return was obtained from the total sale price of the fish. Net return was determined by subtracting all costs from the gross return.

Fig. 4. Photograph of operation of sludge remover.

Table 1
Specification and performance of sludge remover at on station conditions.

Parameter	Characteristics
Pump type	Axial flow
Diameter of pump	102 mm, made with 1.6 mm thick mild steel sheet
Length of pump	1.5 m–6.0 m (Adjustable)
Impeller type	Mixed flow with 5 blades
Source of power	7.5 kW diesel engine, 2100 rpm
Pump speed	1700–1800 rpm
Forward speed	12.50 ± 1.55 m/min
Delivery pipe	102 mm diameter and 30.5 m long (flexible)
Discharge	14.11 ± 2.16 L/s
Theoretical field capacity	0.101 ha/h
Effective field capacity	0.078 ha/h
Field efficiency	77.23%
Water sludge ratio	3.6:1.0 (Weight basis)
Price of sludge remover	US $1026 (BDT 90,000)

3. Results and discussion

3.1. Performance of sludge remover

The first prototype of sludge remover was tested in the pond of FMPE Division, BARI, Gazipur during March–April 2014. The photographic view of operation of sludge remover is shown in Fig. 4. Area of FMPE pond was about 0.26 ha (52 m × 50 m) and depth of water was about 2.5 m. The sludge remover was operated according to the principle of operation. It remover was operated in five blocks of the same pond. The blocks were marked with coloured ropes and poles so that they can be clearly visible. Each block size was 50 m × 100 m. The sludge remover was operated five times in the pond (One time each of five blocks) to get the average performance value. The specification and performance of sludge remover is given in Table 1. The sludge pump was operated at various speeds (1200–2000 rpm) and 1700–1800 rpm was found for getting optimum discharge. The discharges of the 102 mm axial pump for lifting fresh water at the pump speed of 1900–2000 rpm varied from 12.4 to 27.5 L/s for the water head of 5.0 m and 1.0 m, respectively (Hossain et al., 2015). The peak pump efficiency and brake power were found for the discharge of 21 L/s (Fig. 5). Average forward speed of the sludge remover was 12.50 ± 1.55 m/min. The discharge of the sludge pump was measured by volumetric method using the water tank of 3500 L. The average discharge was found to be 14.11 ± 2.16 L/s. The effective field capacity of the sludge remover was 0.078 ha/h. The average field efficiency of the sludge remover was found to be 77.23%. Higher the field efficiency, the more efficient the machine is. The machine similar to sludge remover (tillage machinery) with field efficiency below 75% is said inefficient (Kepner et al., 1987). So, the sludge remover is found reasonably efficient. The sludge remover was operated under the water and sludge was cleaned with eye estimation. So, overlapping could not be avoided by the operator, which might reduced the field efficiency. About 40–50 mm thick sludge (with some mud) can be removed from the fish pond in each operation by the sludge remover. But sludge accumulation ranges 50–70 mm per year in a typical pangasius pond in Bangladesh (Haque et al., 2013). After siltation sludge is deposited in the sludge pit but some smaller sludge particles backflows to the pond with water. These smaller sludge particles did not affect significantly in contamination of water. The discharge of sludge and water mixture was collected in three water containers each of five liter. The average water sludge ratio was found 3.6:1.0 (weight basis). Pictorial view of sludge deposition is shown in Fig. 6. Some minor problems were observed during operation of the sludge remover such as straight moving of the float, turning problem, no backward movement facility, etc. Sometimes, water was discharged instead of sludge. This was due to the uneven bottom bed of the pond. Tree branches, stone or brick pieces and snails on the pond bottom sometimes created barrier in smooth operation of the sludge remover. Overall results of on station trials of the newly developed sludge remover were found satisfactory.

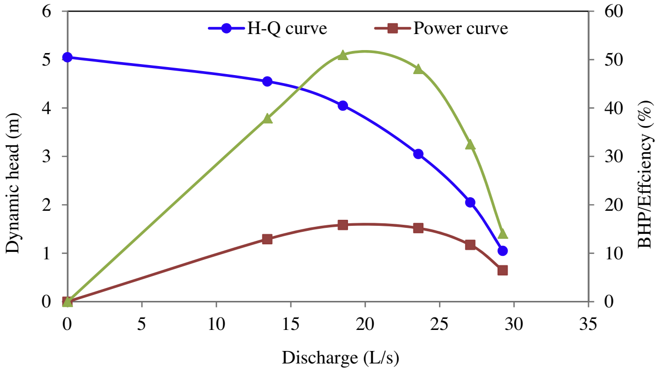


Fig. 5. Characteristic curves of 102 mm axial flow pump.

Fig. 6. Pictorial view of sludge deposition.

3.2. Water quality

Water temperature at morning and afternoon in the fish pond during culture period is shown in Fig. 7. The treatment (sludge removal) and control ponds were in the same place, so water temperatures at a particular time were same. Water temperatures in the afternoon (4:00 pm) were significantly higher ($p \le 0.05$) than morning (7:30 am) temperatures. The mean water temperatures in the morning and afternoon were 17.28 ± 3.89 °C and

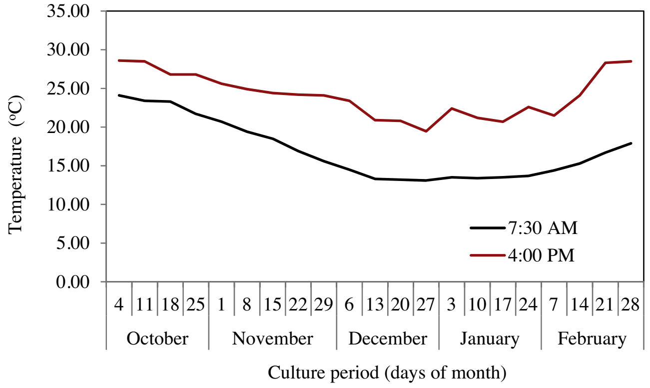


Fig. 7. Water temperature at morning and afternoon in the ponds (both treatment and control) during fish culture.

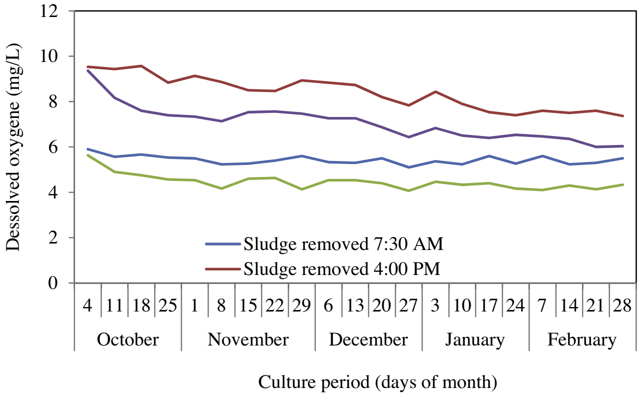


Fig. 8. Dissolved oxygen in the sludge removal and control ponds at morning and afternoon during fish culture.

24.38 ± 2.93 °C, respectively. During the culture period, water temperature in the morning and afternoon varied due to the variation of seasonal air temperature. Water temperature decreased from September to January (winter) and then again increased up to the end of the month of February. Water temperature is an important factor for water chemistry. with increase of water temperature, dissolved oxygen, carbon dioxide and pH of water also increase (Wurts and Durborow, 1992).

Dissolved oxygen (DO) in the sludge removal and control ponds during fish culture are shown in Fig. 8. DOs in the pond water at afternoon (4:00 pm) were found significantly higher ($p \leq 0.05$) than that of in the morning (7:30 am) for both the sludge removal ponds and control ponds. So, DOs in the afternoon were higher due to day light, photosynthesis, higher temperature than morning times. DO concentration in ponds fluctuates on a 24 h basis. This fluctuation is called a diurnal oxygen cycle. Dissolved oxygen increases during daylight hours when photosynthesis occurs and decreases at night when respiration continues but photosynthesis does not. DO concentration below 5 mg/L is harmful to fish (Francis-Floyd, 2014). Therefore, DOs in the afternoon of sludge removal and control ponds were safe for fish health. DOs in the pond sludge removal ponds were significantly higher ($p \leq 0.05$) than control ponds in afternoon and morning. So, fishes in the sludge removal ponds got more DOs than control ponds. After one month of stocking, the DOs of control ponds in the morning time reduced below 5 mg/L (4.61 ± 0.51) that hampers the fish health and growth. Francis-Floyd (2014) reported that one of the main cause of oxygen depletion in water is the increase of organic waste entering the water (i.e., manure from feedlots, septic tank waste water, and excess fish feed). Therefore, sludge removal significantly improved the DO in the fish ponds during culture. Teodorowicz (2013) reported that clarifying ponds had a positive impact on the quality of water in terms of total phosphorus and BOD at the rate of 25.8 and 32.7%, respectively.

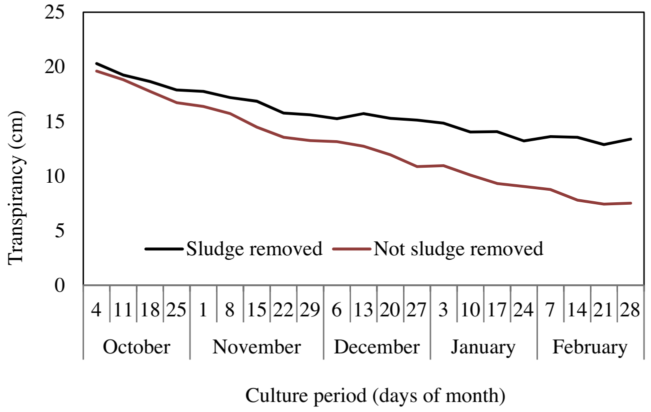


Fig. 9. Transparency of water in the sludge removal and control ponds during fish culture.

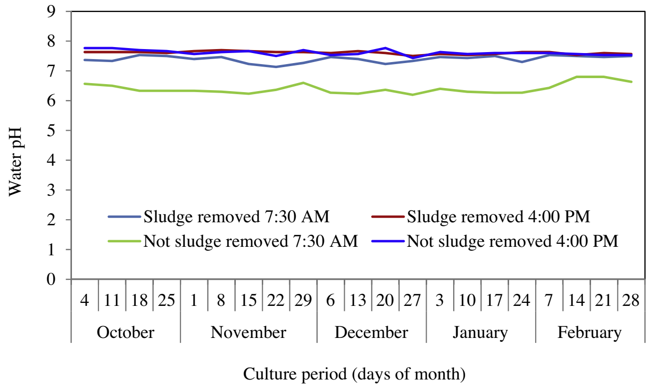


Fig. 10. Water pH in the sludge removal and control ponds at morning and afternoon during fish culture.

Water transparency in the sludge removal and control ponds during fish culture are shown in Fig. 9. Water transparency represents cleanliness of water in the fish ponds. It is revealed from the figure (Fig. 9) that water transparency decreased with the culture period due the discoloration of water caused by application of feeds and growth of different planktons. Water transparency in the sludge removal pond (16.21 ± 2.53 cm) was found significantly higher ($p \leq 0.05$) than control pond (13.40 ± 4.27 cm) during fish culture. This may be due to that water of sludge removal pond became clearer than control pond.

Water pH is an important parameter for fish health in the pond. The desired range of pH for fish production is 6.5–9.0. The water pH below 4.0 and above 11.0 causes the death of fish (Wurts and Durborow, 1992). Water pH of sludge removal ponds (at 7:30 am and 4:00 pm) and control ponds at 4:00 pm varied from 7.13 to 7.77 which were in the desired range of water pH. But water pH of control pond varied from 6.20 to 6.8 which was critical range for desired fish growth (Fig. 10). Therefore, pH of water in the fish pond can be improved through sludge removal.

Unionized ammonia in the sludge removal and control ponds during fish culture is given in Fig. 11. Unionized ammonia in the sludge removal pond (0.82 ± 0.22 mg/L) was significantly lower than that of control pond (1.50 ± 0.59 mg/L). The main source of ammonia in fish ponds is fish excretion. The rate at which fish excrete ammonia is directly related to the feeding rate and the pro-

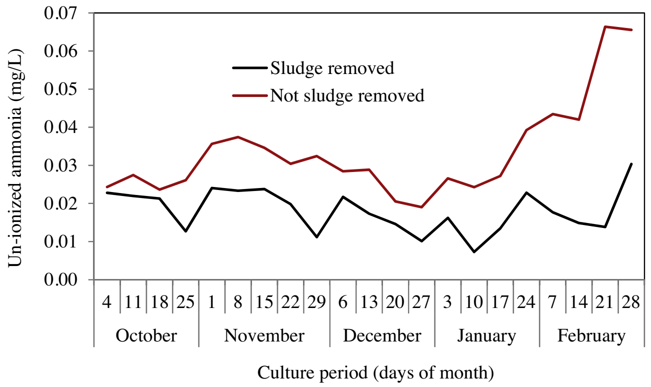


Fig. 11. Un-ionized ammonia in the sludge removal and control ponds during fish culture.

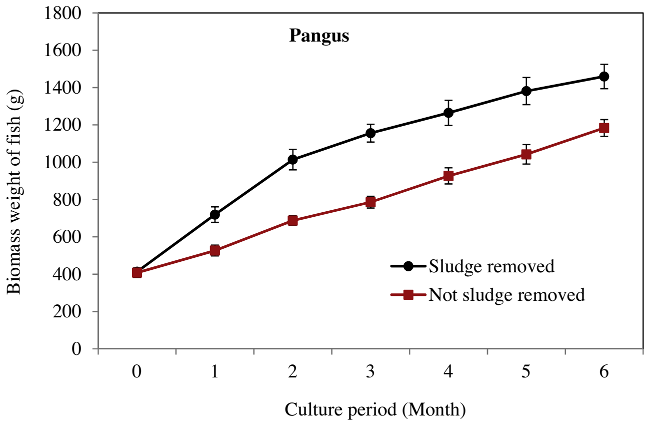


Fig. 12. Growth of pangus fish in the sludge removed and control ponds during culture.

tein level in feed. Fecal solids excreted by fish and dead algae settle to the pond bottom, where they decompose. The decomposition of these organic matters produces ammonia, which is diffused from the sediment into the water column. In fish ponds, it is extremely unlikely that unionized ammonia would accumulate to a concentration that would become toxic enough to kill fish (Hargreaves and Tucker, 2004). After the removal of sludge, unionized ammonia concentration in the fish pond was reduced. But in control pond, sludge accumulation increased the unionized ammonia concentration.

3.3. *Growth of fish*

Same stocking density and feeds were provided in all sludge removal and control ponds during the fish culture. As a major species growth of pangus fish in the sludge removal and control ponds during culture is shown in Fig. 12. It is observed that fish weights increased almost linearly with the culture period. But significantly higher ($p \leq 0.05$) fish growth was found in sludge removal ponds than those of control ponds. The reason might be that fishes in sludge removal ponds enjoyed a favourable environment for their growth. On the other hand, water of control pond was contaminated with sludge and produced harmful gases and chemicals, reduced DO that retarded the growth of fish. Similar results were found for tilapia fish (Fig. 13). But tilapia in control ponds harvested one month before the sludge removed ponds due to beginning of mortality.

Performance of sludge removed and control ponds used for pangas-tilapia-carp fish polyculture is given in Table 2. It is observed that stocking density of fish fingerlings in all the ponds was almost same. Survival rate of sludge removed pond was little higher than control pond but they were statistically alike. But total production and net yield (per ha) of sludge removed and control were found to be significantly ($p \leq 0.050$) higher than the control pond. FCR was better for sludge removed pond than the control pond. The result revealed that comparatively less amount of feed was utilized in sludge removed pond than the control pond for fish growth out. This was due to that sludge removal had favourable environment i.e. higher DO, higher water pH, lower unionized ammonia, less harmful gas production resulted from deposition of sludge. SGR of fish grown in sludge removed pond found higher than that of control pond. SGR represent the average growth rate of fish during culture period. Higher SGR indicated the impact of sludge removal in the fish pond. Due to higher fish production, the net return obtained from sludge removal pond was 7300 US$/ha followed by the control pond was 3000 US$/ha. The benefit cost ratio (BCR) of sludge removed ponds and control ponds were found to be 5.40 and 2.34, respectively. Therefore, sludge removal in intensive fish culture was found to be economically profitable.

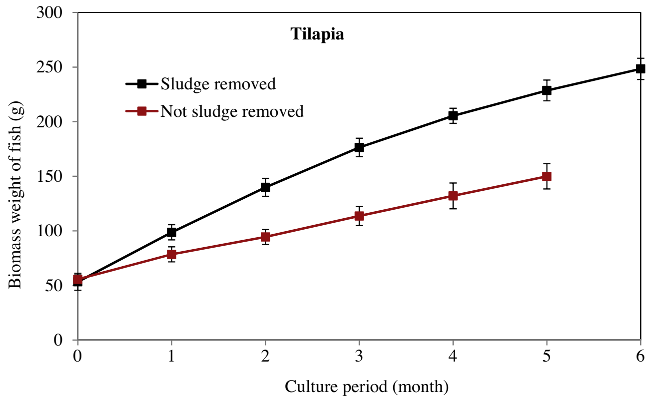


Fig. 13. Growth of tilapia fish in the sludge removed and control ponds during culture.

Table 2
Performance of sludge removal and control fish ponds.

Treatment Culture type	Sludge removal Polyculture[a]	Control Polyculture[a]
Stocking (Number/ha)	47,887 ± 504	47,946 ± 584
Survival rate (%)	90.89 ± 1.90	87.89 ± 0.83
Total production (t/ha)	27.17 ± 2.21	18.97 ± 1.85
Net yield (t/ha)	23.91 ± 2.19	16.08 ± 1.81
FCR	1.64 ± 0.04	1.90 ± 0.06
SGR (% per day)	0.80 ± 0.03	0.71 ± 0.02
Net return (US$/ha)	7300 ± 156	3000 ± 143
Benefit cost ratio (BCR)	5.40 ± 0.06	2.34 ± 0.04

[a] Poly-culture = Pangus-tilapia-carp (60% Pangus, 20% tilapia and 20% carp).

Acknowledgement

The authors are very thankful and duly acknowledge to USAID and CSISA-BD, WorldFish, CYMMIT and IRRI for technical and financial supports. The authors are also grateful to BARI and WorldFish, Bangladesh and South Asia for providing physical and logistic supports to carry out the research successful. Finally we would like to thank our farming households, staffs, worker in the workshop who extended support during the study.

References

Abdelhamid, A.M., Khalil, F.F., Ragab, M.A., 1996. Survey of aflatoxin and ochratoxin occurrence in some local feeds and foods. In: Proceeding of

Conference on Food Borne Contamination and Egyptian's Health, Mansoura University, November 26–27, pp. 43–50.

Abdelhamid, A.M., El-Mansoury, A.M., Osman, A.I., El-Azab, S.M., 1999. Mycotoxins as causative for human food poisoning under Egyptian conditions. J. Agric. Sci. 24, 2751–2757, Mansoura University.

Abdelhamid, A.M., Mehrim, A.I., Alkatan, M.A., 2014. Effects of feeding fish dried-treated sewage sludge part 1: growth performance, feed utilization and chemical composition. Research Report. Department of Animal Production, Faculty of Agriculture, Al-Mansoura University, Egypt.

Anh, Pham Thi, Kroeze, C., Bush, Simon R., Mol, Arthur P.J., 2010. Water pollution by Pangasius production in the Mekong Delta, Vietnam: causes and options for control. Aquac. Res. 42 (1), 108–128.

Belton, B., Karim, M., Thilsted, S., Jahan, K.M., 2011. Review of aquaculture and fish consumption in Bangladesh. Studies and Reviews 2011-53. The WorldFish Center, November, 2011.

Birch, S., Bell, R., Nair, J., PHung, C.V., 2010. Feasibility of vermicomposting aquaculture solid waste on the Mekong Delta, Vietnam: a pilot study. Dyn. Soil Dyn. Plant 4 (1), 127–134.

Boyd, Claude E., Rajts, Francois, Firth, James, 2011. Sludge management at BAP pangasius farm cuts TAN, BOD5, TSS in discharges. Global Aquac. Advocate (September).

Bullock, G.L., Summerfelt, S.T., Noble, A., Weber, A.W., Durant, M.D., Hankins, J.A., 1997. Ozonation of a recirculating rainbow trout culture system: I. Effects on bacterial gill disease and heterotrophic bacteria. Aquaculture 158, 43–55.

CSISA-BD, 2011. Expansion of the Cereal Systems Initiative for South Asia (CSISA) in Bangladesh. Annual Work Plan for The First Year. October 2010–December 2011. Prepared by International Rice Research Institute (IRRI), World Fish Centre (WF) and International Wheat and Maize Research Institute (CIMMYT), Bangladesh, April 2011.

Chen, S., Coffin, D., Malone, R.F., 2007. Sludge production and management for recirculating aquacultural systems. J. World Aquac. Soc. 28 (4), 303–315.

Chowdhury, M.H., Maharjan, K.L., 2000. Increasing efficiency of pond fish production in rural Bangladesh. In: Proceedings of 10th IIFET (International Institute of Fisheries Economics and Trade) Conference, July 10–14, 2000, Corvallis, Oregon, USA.

DHI, 2015. Improved Sludge Management in Land-Based Aquaculture—DHI Case Story v2.0(1). The Danish Ministry of Science Innovation and Higher Education, Hørsholm, Denmark www.dhigroup.com.

Davidson, J., Summerfelt, S.T., 2005. Solids removal from a coldwater recirculating system-comparison of a swirl separator and a radial-flow settler solids removal from a coldwater recirculating system-comparison of a swirl separator and a radial-flow settler. Aquac. Eng. 33, 47–61.

Dey, M.M., Alam, M.F., Weimin, M., Piumsumbun, S., Bhatta, R., Koeshendrayana, S., Paraguas, F.J., 2005. Constraints to higher yield in carp farming: implications for future genetic research. In: Penman, D., Gupta, M.V., Dey, M.M. (Eds.), Carp Genetic Resources for Aquaculture in Asia. , pp. 114–120, WorldFish Center Technical Report 65, 152pp.

DoF, 2014. Fisheries Resource Survey System. Department of Fisheries, Ministry of Fisheries and Livestock, Dhaka, Bangladesh.

Emerson, K., Russo, R.C., Lund, R.C., Thurson, R.V., 1975. Aqueous ammonia equilibrium calculations: effects of pH and temperature. J. Fish. Res. Board Can. 32, 2379–2383.

FAO, 2014. National Aquaculture Sector Overview of Bangladesh. Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department, Rome, Italy.

Francis-Floyd, Ruth, 2014. Dissolved oxygen for fish production. Publication No. FA27, Fisheries and Aquatic Sciences Department, UF/IFAS Extension, Visit the EDIS website at http://edis.ifas.ufl.edu.

Haque, M.M., Monira, M.S., Salam, M.A., Shinn, A.P., Little, D.C., 2013. Use of pangaosius pond sediment for rooftop bag gardening for rural-urban integrated aquaculture-horticulture. Aquac. Asia 18 (4), 21–23.

Haque, M.M., Belton, B., Alam, M.M., Ahmed, A.Z., Alam, M.R., 2016. Reuse of pond sediments as fertilizer for fodder grass production in Bangladesh: potential for sustainable intensification and improved nutrition. Agric. Ecosyst. Environ. 216, 226–236.

Hargreaves, John A., Tucker, Craig S., 2004. Managing ammonia in fish ponds. SRAC (Southern Regional Aquaculture Center) Publication No. 4603. The United States Department of Agriculture, Cooperative State Research, Education, and Extension Service.

Hossain, M.A., Hoque, M.A., Miah, M.S., Hassan, M.S., 2015. Development and performance evaluation of an axial flow pump. Annual Research Report. Farm Machinery and Postharvest process Engineering Division, Bangladesh agricultural Research Institute, Gazipur-1701, Bangladesh.

Kepner, R.A., Bainer, R., Barger, E.L., 1987. Principles of Farm Machinery. CBS Publishers and Distributers, Dehli-110032, India, p. 525.

Sayeed, M.A.B., Hossain, G.S., Mistry, S.K., Huq, K.A., 2008. Growth performance of Thai pangus (*Pangasius hypophthalmus*) in polyculture system using different supplementary feeds. Univ. J. Zool. Rajshahi Univ. 27, 59–62.

Teodorowicz, Mariusz, 2013. Surface water quality and intensive fish culture (MonograpH). Arch. Pol. Fish. 21, 65–111.

Turcios, A.E., Papenbrock, J., 2014. Sustainable treatment of aquaculture effluents-what can we learn from the past for the future? Sustainability 6, 836–856.

Watanabe, W.O., Ellis, S.C., Chaves, J., 2001. Effects of dietary lipid and energy to protein ratio on growth and feed utilization of juvenile mutton snapper (*Lutjanus analis*) fed is nitrogenous diets at two temperatures. J. World Aquac. Soc. 31, 29–40.

Wurts, William A., Durborow, Robert M., 1992. Interactions of pH, carbon dioxide, alkalinity and hardness in fish ponds. SRAC (Southern Regional Aquaculture Center) Publication No. 464. United States Department of Agriculture.

Zhou, Li, 2015. Investigations of ammonia nitrogen in aquaculture: the methodology, concentrations, removal, and pond fertilization (Ph.D. dissertation). Graduate Faculty of Auburn University, Auburn, Alabama, USA.