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BIOLOGICAL TREATMENT OF DOMESTIC WASTEWATER FOR AQUACULTURE

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ABSTRACT

Domestic sewage contains important nutrients for the growth of plants and is used for aquaculture in several parts of the world. The campus of Indian Institute of Technology (IIT), Kharagpur generates 14.29 lakh liters day^{-1} of sewage. Only 17% of the total sewage is going to the existing ponds while the remaining 83% is wasted due to leakage in the underground drainage system. There is a possibility of pollution of soil and ground water around the IIT, Kharagpur campus. A study was initiated to assess the present situation and to design a sewage-fed aquaculture farm on the campus. The area was physically surveyed, soil samples and meteorological data collected and analysed. Based on the collected information, a model of sewage-fed aquaculture farm was designed. This would utilize the nutrients present in the sewage and would reduce the risk of pollution of soil and ground water in the area.

The data collected from the proposed sewage treatment aquaculture farm show that the desired dissolved oxygen level (> 5 mg/l) was achieved on 4th day from 1 mg/l, COD concentration (< 50 mg/l) on 6th day from 350 mg/l, TSS (80 mg/l) on 5th day from 350 mg/l, BOD concentration (<20 mg/l) on 6th day from 180 mg/l and ammonium-nitrogen concentration (0.2-3 mg/l) was achieved on 5th day.

Economic analysis of the model sewage-fed aquaculture farm shows that there will be an annual profit of Rs. 766,014/- on an annual investment of Rs. 677,986/- (excluding cost of land and sewage water). The farm will produce 35,000 kg of fish per year and will also generate employment of 2,545 men-days per year.

Keywords: domestic sewage, oxidation, aquaculture, algae, economics.

INTRODUCTION

Cities consume resources and produce both liquid and solid waste. With the increasing population in the country, the quantity of wastewaters generated has been increasing beyond the treatment capacities. The disposal of these wastes is increasingly becoming a problem. However, waste must be regarded as a resource for the sustainable rural and urban development. Agriculture has always been an intrinsic part of Asian cities. In many Asian cities, the composting of separated solid waste and recycling of waste and sewage water used to be a tradition. These conventional methods are being renamed as urban agriculture which are found to be providing employment, food and nutrition and helping in land management and environmental improvement (Arceivala, 1981).

Intense efforts are being made at treating the domestic sewage to make the effluents suitable for discharge into the natural waters. The traditional practices of recycling sewage through agriculture, horticulture and aquaculture, being basically biological processes, have been in vogue in several countries. The sewage-fed fish culture in bheries of Calcutta is world-famous. The emphasis in these practices has been on the recovery of nutrients from the wastewater. Taking ideas from these practices and deriving from the new databases in different disciplines of wastewater management, aquaculture is being proposed and standardized as a tool for treatment of domestic sewage (CIFA, 1998).

Fish production in a water body is mainly based on the food or planktons available in the water body, which in turn depends upon the nutrients available in the water. It has been considered that nitrogen and phosphorous are the two nutrients mainly responsible for the plankton production and growth. So the enrichment of these nutrients would increase the fish production. But if it exceeds certain limit, it may cause nuisance algal blooms, subsequently depletion of dissolved oxygen (DO) and fish kill etc. (Edwards *et al*., 1990).

Proper design of an aquaculture farm is required for efficient use of the resources available in the sewage water. By the proper design only, we can use more effectively and more efficiently the available water resources and the land area. In India a lot of fish farms are running by using sewage water but there is no proper designed sewage-fed aquaculture farm, in the laterite soil zone, is available. This study was formulated to make a proper design of an aquaculture farm by using sewage water in laterite soil zone.

There is a tremendous need to develop reliable technologies for the treatment of domestic wastewater in developing countries. Such treatment systems must fulfill many requirements, such as simple design, use of non-sophisticated equipment, high treatment efficiency, and low operating and capital costs. In addition, consonant with population growth and increase in urbanization, the cost and availability of land is becoming a limiting factor, and ‘‘footprint size’’ is increasingly becoming important in the choice of a treatment system (Ghosh *et al*., 1995).

Health issues and waste-fed aquaculture

Based on recommendations by WHO (1989) and bacterial quality standards and threshold concentrations for fish muscle, Pullin *et al*., (1992) published guidelines for domestic wastewater reuse in aquaculture:

- a minimum retention time of 8-10 days for raw sewage;
- a tentative maximum critical density of 105 total bacteria/ml in wastewater-fed fish pond water;
- absence of viable trematode eggs in fish ponds;
- suspension of wastewater loading for 2 weeks prior to fish harvest;
- holding fish for a few hours to facilitate evacuation of gut contents;
- < 50 total bacteria /g of fish muscle and no *Salmonella*;
- good hygiene in handling and processing, including evisceration, washing and cooking well; and
- use as high-protein animal feed if direct consumption of fish is socially unacceptable.

Anecdotal evidence does not indicate significantly increased risk to public health from consumption of fish raised in most reuse systems but scientifically based data are almost entirely lacking to support such a contention. It was recognized at the outset (WHO, 1989) that public health standards should be based on epidemiological rather than microbiological guidelines *i.e.*, on actual rather than on potential risk, and this has been detailed by Strauss (1996). There is evidence from India (Pal and Das Gupta, 1992) and Egypt (Easa *et al*., 1995) that the microbiological quality of fish cultured in wastewater-fed ponds is better than that of freshwater fish from many other water bodies and surface waters which have been polluted unintentionally. It can be argued that it is safer to consume fish cultured in a well managed and monitored, wastewater-fed system than to rely on wild fish caught from increasingly polluted and unregulated surface waters.

MATERIALS AND METHODS

The site selected for the present study was the experimental farm of the Department of Agriculture and Food Engineering, Indian Institute of Technology, Kharagpur. It is located at $22^0$19' N Latitude and $87^0$19' E Longitude with an altitude of 48m above mean sea level. It lies in the State of West Bengal of Eastern India. The study area receives about 1500mm mean annual rainfall, about 78% of which is concentrated during rainy season from June to September. The mean minimum and maximum air temperature are 10^0C in January and 40^0C in May. In the corresponding months the mean relative humidity varies between 18-89% and 15.5-90.5%, respectively.

Presently the sewage water from the IIT Kharagpur campus goes to sewage well and when the well gets filled up to a particular level then this water is pumped out and supplied to a pond. There are three ponds, two are oxidation ponds and one is an overflow pond. In the oxidation pond approximately 45cm water is there and the overflow/fish pond is totally dry at present. The sewage water from the oxidation pond is lost due to seepage and evaporation. The total area of the entire land including ponds and the available nearby land area is about 45 ha.

Experimental setup

The experiment was carried out using lab scale oxidation ponds with 54 liters capacity each. The experiment was performed from November 2004 to March 2005. The domestic wastewater was collected from the inlet of oxidation pond and observations were taken for nitrate, nitrite, ammonium and phosphate, fecal bacteria, dissolved oxygen, temperature, pH, biological oxygen demand (BOD) and chemical oxygen demand (COD). One such data set for each of the oxidation pond was collected. Water analysis was done for a lab scale oxidation pond filled with 40 liters of wastewater, treated with algal concentration of 10 gm/l. When the water quality was appropriate to aquaculture, it was cultured with fish available (100 Nos. /m^3). After the culture, water quality parameters were taken. Sampling and measurements were done at 9A.M.

Model of wastewater treatment

The model of the proposed sewage treatment aquaculture farm is shown in Figure-1.

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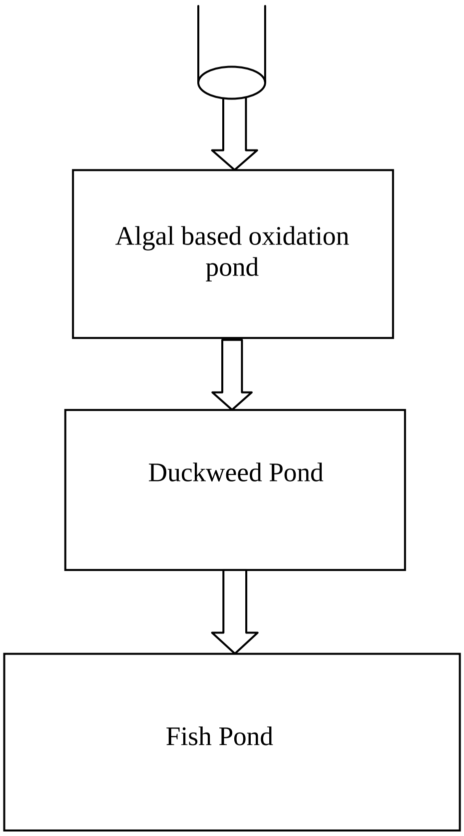

Figure-1. Model of the proposed wastewater treatment for aquaculture purpose.

RESULTS AND DISCUSSION

The characteristics of the raw sewage available from IIT Khargpur campus is shown in Table-1.

Table-1. Characteristics of the raw sewage available from IIT Khargpur campus.

S. #	Parameter	Concentration
1.	**B.O.D.** (mg/l)	180
2.	**C.O.D.** (mg/l)	350
3.	**Dissolve Oxygen** (mg/l)	1.0
4.	**Temperature** (°C)	25
5.	**Total Suspended Solids** (mg/l)	350
6.	**pH**	7. 10
7.	**Nitrate** (mg/l)	0.12
8.	**Nitrite** (mg/l)	0.2
9.	**Ammonium** (mg/l)	4.25
10.	**Phosphate** (mg/l)	0.24
11.	**Most Probable Number/100ml**	920

Experimental results

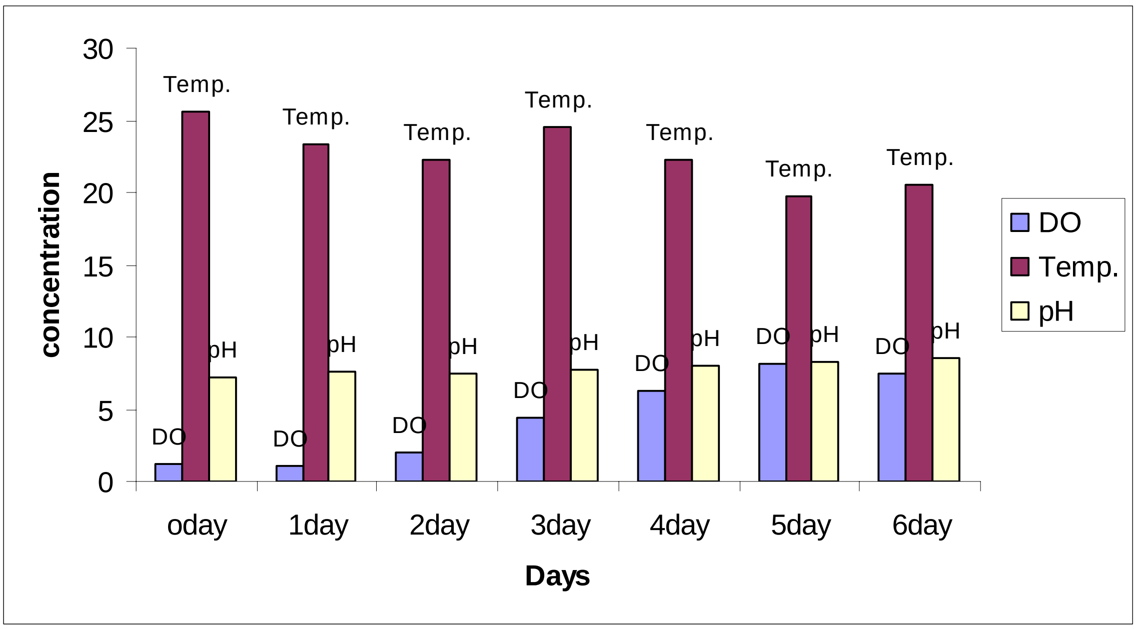

Figure-2a. Performance of lab-scale oxidation pond with algae concentration (10 g/l).

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The results obtained by conducting lab-scale experiments on oxidation pond based on algae concentration (10g/l) are presented in Figure-2a. It was observed that the desired dissolved oxygen level concentration (> 5 mg/l) was achieved on 4th day, making treated wastewater suitable for aquaculture. Diurnal fluctuations of pH will occur due to the amount of aquatic life within a pond. With higher algae concentration, more CO_2 is removed from the system and hence pH levels will rise. The reverse process will occur at night when more CO_2 is produced, leading to a drop in pH level. Slight increase in pH level was observed.

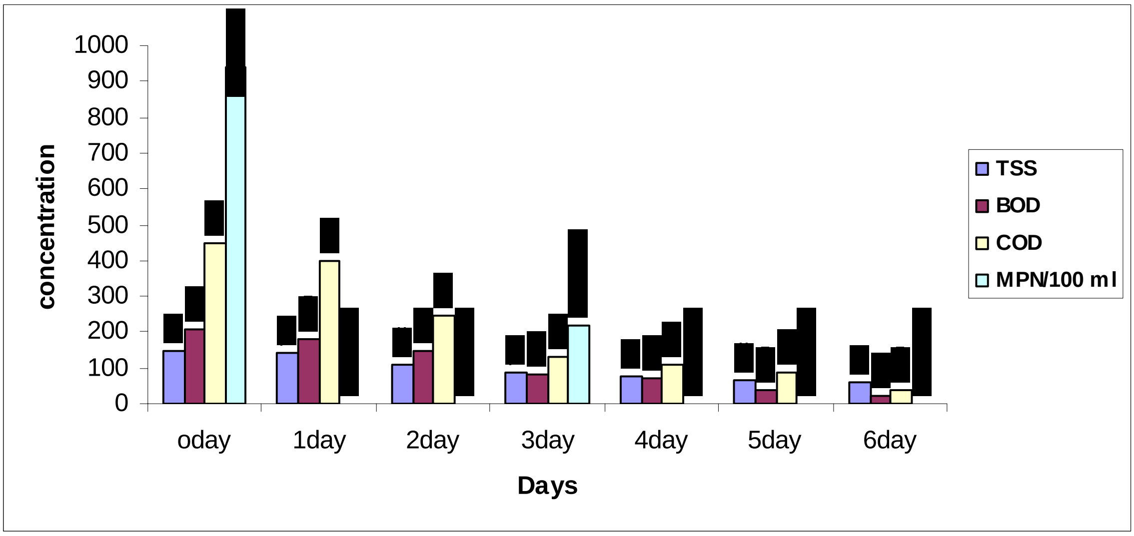

Figure-2b. Performance of lab-scale oxidation pond with algae concentration (10 g/l).

As shown in Figure-2b, the acceptable COD concentration (< 50 mg/l) for aquaculture was achieved on 6th day. This concentration was reported to be favorable for aquaculture by APHA (1989); Boyd and Tucker (1992). Similarly the acceptable TSS and BOD were achieved on 5th and 6th days, respectively. The requirement of BOD concentration for aquaculture (< 20 mg/l) was reported by Forsberg *et al*. (1996) and TSS concentration (80 mg/l) was reported by Larsen, (1982).

As shown in Figure-2c, it was observed that the requirement of ammonium-nitrogen level concentration (0.2-3 mg/l) was achieved on 5th day. Ammonia levels will depend on the temperature of the pond's water and its pH. For example at a higher temperature and pH, a greater number of ammonium ions are converted into ammonia gas thus causes an increase in toxic ammonia levels within the aquaculture pond.

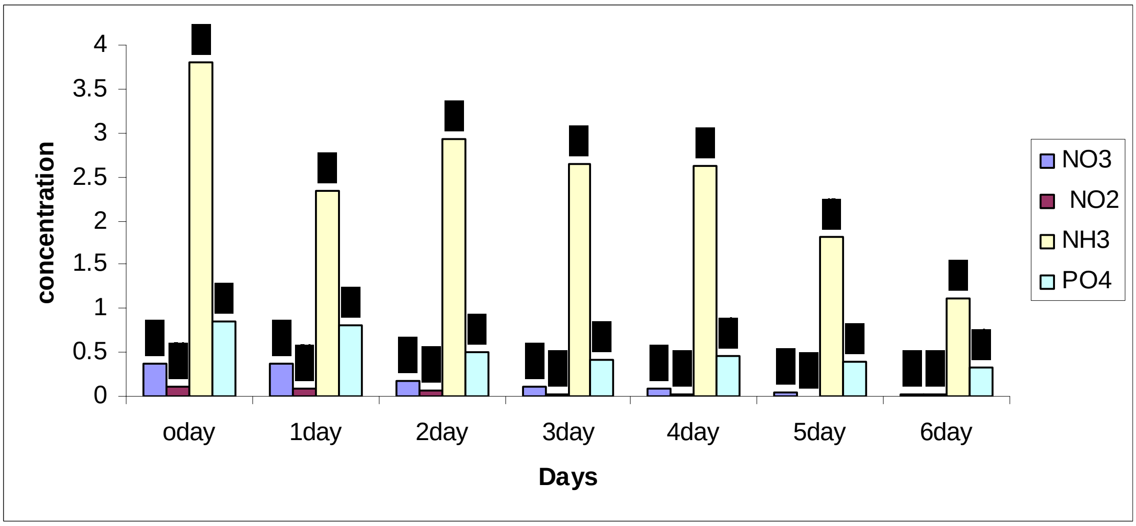

Figure-2c. Performance of lab-scale oxidation pond with algae concentration (10 g/l).

The ammonium-nitrogen level concentration (0.2-3 mg/l) for aquaculture was reported by Boyd (1998)**.** After doing experiments, the concentration of nitrate, nitrite and phosphate were found in permissible limit for aquaculture. The required concentrations of Nitrate, Nitrite

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and Phosphate for aquaculture 0.0 to 3.0mg/l, < 0.3mg/l and 0.01 to 3.0mg/l was reported by Wedemeyer, (1977).

The same type of observational variations was obtained based on the experiments conducted with 15gm/l algal concentrations. Based on these experimental results, it can be concluded that the available sewage can be used for aquaculture. In the proposed model of wastewater treatment (Figure-1), two ponds can be used in sequence. Sewage coming from pipeline should first be treated with algal based oxidation pond to increase the DO level. While subsequently it should be treated in duckweed pond before it is used for aquaculture. Duckweed pond can be used to reduce harmful nitrite and ammonia level in sewage.

Economic analysis

The emphasis in aquaculture is on the production of human food, but due to increasing energy costs and environmental pollution associated with conventional wastewater, there is considerable interest in potential of aquaculture as a simple and economically effective alternative for human waste treatment. It has been appreciated that aquaculture can provide an effective treatment alternative to conventional wastewater treatment, and in addition provides an economic return to defray the operating cost.

Table-2. Unit cost of establishment of an 8 ha pilot scale sewage-fed aquaculture farm with 5 ha water area.

Sr. #	Items for fixed capital cost	Initial cost (Rs.)	Economic life (year)	Depreciation/ year (Rs.)
1.	**Cost of land** (8 ha)	Available free of cost from IIT Kharagpur		
2.	**Cost of earthwork for 5 ha water area and dyke**	500,000	-	-
3.	**Structural cost**			
	a. Pipelines for sewage distribution system	1,50,000	25	6,000
	b. Tube well with pump,	1,50,000	20	7,500
	c. Watchman’s residential quarters (shade type) - 2 Nos.	100,000	25	4,000
	d. Fish breeding hatchery shade	100,000	25	4,000
	e. Lab/office/stores shade with fittings	600,000	25	24,000
	f. Farm fencing	200,000	10	20,000
	g. Farm electrification with halogen lamps	80,000	25	3,200
4.	**Farm inventory**			
	a. Generator	1,00,000	20	5,000
	b. Telephone	10,000	-	-
	c. Sewage distribution pump set with suction pipe, foot valve and delivery pipe	50,000	20	2,500
	d. Nets, fishing material, farm implements and hapas	40,000	10	4,000
5.	**Cost of fish seed and brooders to initiate working of the farm**	30,000	-	-
		21,10,000		**80,200**

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Table-3. Recurring expenditure to operate an 8 ha fish farm with 5 ha water area for one year.

Sr. #	Items for capital cost	Amount (Rs.)
1.	**Factor service**	
	a. Tax for land and structure	1,500
	b. Wages for 4 regular watchmen per year	1,09,500
	c. Wages for 6 casual fishermen for 4 months per year	54,000
	d. Wages for farm manager on regular basis per year	36,000
	e. Pond preparation, weed clearance, etc.	5,000
	f. Cost of diesel, electricity, etc.	30,000
	g. General maintenance	35,000
		2,71,000
2.	**Material input** (towards)	
	a. Spawn production	
	i. Cost of pituitary glands (4,000mg) @ Rs. 4/mg	16,000
	ii. Cost of distilled water, saline, glycerol, etc.	200
		16,200
	b. Fry production	
	i. Cost of lime (500 kg) @ Rs. 2/kg	1,000
	ii. Pest control and management	2,000
	iii. Supplementary feed (500 kg) @ Rs. 3 /kg	1,500
		4,500
	c. Fingerling production	
	i. Cost of lime (120 kg) @ Rs. 2/kg	240
	ii. Supplementary feed (1000kg) @ Rs. 3/kg	3,000
		3,240
	d. Farm office/ lab	
	i. Stationary	2,200
	ii. Chemicals, disinfectants, soaps, etc.	2,500
	Total recurring cost	**2,99,640**

Table-4. Annual investment.

Sr. #	Item	Amount (Rs.)
1.	Depreciation on fixed capital cost per year	80,200
2.	Interest on fixed capital cost @ 12% per year	2,53,200
3.	Recurring cost (working capital) per year	2,99,640
4.	Annual interest on working capital @ 15%	44,946
	Total annual investment	**6,77,986**

Table-5. Expected annual return.

Sr. #	Sale proceeds of farm produce	Quantity	Rate	Amount (Rs.)
1.	Spawn (surplus after farm need)	86 (lakh)	500 (Rs./lakh)	43,000
2.	Fry (surplus after farm need)	23 (lakh)	7,000 (Rs./lakh)	1,61,000
3.	Fingerlings (surplus after farm need)	30 (thousand)	500 (Rs./thousand)	15,000
4.	Table-size fish	35,000 (kg)	35 (Rs./kg)	12,25,000
	Total annual return			**14,44,000**

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Table-6. Summary.

Annual Investment (Rs.)	Annual Turnover (Rs.)	Annual Profit (Rs.)	Fixed Capital Cost (Rs.)	Return over Investment	Profit to Turnover	Return over Fixed Capital
6,77,986	**14,44,000**	**7,66,014**	**21,10,000**	**113%**	**53%**	**36%**

CONCLUSION

Supply of IIT Kharagpur sewage water, after biological treatment, to the proposed aquaculture farm in this area (laterite soil) would reduce pollution of drinking water in and around the IIT Kharagpur campus and the nutrients present in the sewage would be utilized by the fish cultured in the ponds.

Economic analysis of the proposed model of sewage treatment aquaculture farm and the proposed cultural practices, shows that there will be an annual profit of Rs. 7,66,014/- on an annual investment of Rs. 6,77,986/- (cost of land and sewage water are not included as these are expected to be available free of cost). The farm would produce 35,000 kg of fish/year and would generate employment of 2,545 men-days per year.

At present only 17% of the total sewage is coming to the oxidation ponds while the remaining 83% is wasted due to leakage in the underground drainage system. So, there is a possibility of pollution of soil and ground water. The proposed aquaculture farm would utilize the nutrients present in sewage and thus eliminate the risk of pollution of soil and ground water.

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