DESIGN AND MANAGEMENT OF EL-NENAEIA FISH FARM: AS A RECIRCULATING AQUACULTURE SYSTEM

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ABSTRACT

El-Nenaeia Company has developed a commercial fish production demonstration utilizing water recycle technology developed at Banha University, Faculty of Agriculture, Agricultural Engineering Department. The fish production system is designed in a 32.0 m long by 12.0 m wide. Fish production activities began in the spring of 1998. The facility is designed to produce 30 tons of fish annually, with the first crop being tilapia. The project is being operated as a public demonstration of this technology, with biological, engineering and economic data being collected by research personnel at El-Nenaeia Company. This paper outlines the design of the recirculating system technology used to recycle water through the main fish production tanks.

Keywords : Recirculating system; Biological filter media.

1. INTRODUCTION

Aquatic production systems are typically classified according to type (static system "open system", flow-through system "recycle system", raceway "reuse system" and cage system), biomass density (extensive, semi-intensive, intensive and super intensive), and feeding practices (natural and artificial feeding), Krom et al., (1989).

In extensive system, fish are grown in an environment similar to their natural habitat with no outside food or aeration. The water is required to perform several functions: provide physical living space for the fish, supply

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dissolved oxygen from the atmosphere, dilute toxic metabolic wastes, and serve as the medium in which food organisms for the fish are naturally propagated.

In stagnant pond culture of tilapia, stocking densities up to 10 fish m^{-2} might be employed (Balarin, 1984). However, densities beyond 8 fish m^{-2} have been detrimental for the fish due to the build-up of waste metabolites in the pond water (Zohar et al., 1984).

In Egypt, the extensive system is predominant. One feddan consumes 10000 m^3 of water annually and produce 2100 kg of fish. This is not suitable to the shortage of water and land. Furthermore, it mainly depends on drainage water of agriculture, where pollution most probably occurs. By law, the ministry of public affairs does permit raising fish on fresh water.

Intensive fish culture has many advantages over extensive rearing. For example, the water volume is now required to provide only physical living space for the fish. Its flow through the ponds, raceways, or tanks (often termed rearing units) is used to deliver the required amount of dissolved oxygen. Metabolic wastes are simply flushed away. Artificial diets formulated to meet specific nutritional requirements and fed under controlled conditions provide the food supply. At a given feeding rate, the fish density that can be achieved becomes limited mostly by the rate of water flow through the rearing units rather than by the water's volume and surface area. Intensive culture generally also requires less space than extensive culture methods and a greater degree of control over rearing conditions is usually possible. Tanks sheltered from the weather can be constructed and the water supply can be heated, cooled, filtered, treated with ultraviolet (UV) light to inactivate pathogens, or circulated through biological filter systems to remove ammonia and then be reused. Feeding can easily be mechanized and automated. For these reasons, the trend in fish culture worldwide has been toward more intensive conditions.

Aquaculture tank production systems based on water reuse or recycling are designed by a trial and error approach. This may be because of lack of interest by engineers in aquaculture or simply because the designer, not being engineer, has failed to realize that there was another way. The fish culturist and engineer must work together to explore ways to improve the biological, environmental (water quality) and facility design factors which may lead to increase intensity without added cost. (Timmons & Losordo, 1994)

Ali (1999) has established the technical parameters required to construct a semi intensive fish farm and verified his results. The current work presents a commercial fish farm designed and operation based on these findings. The main objective of the present work is to evaluate technically and economically this farm.

3. MATERIALS AND METHODS

The main target of this farm is to produce 30 tons fish annually. To achieve this, design of the farm was carried out, using the water recycling system, with initial and final average weights of individual tilapia fish 5.0 and 250.0g, respectively.

3.1. System Description

Figure (1) illustrates the design of the water recycle system. It consists of the following components.

3.1.1. Fish Tank:

Three circular concrete tanks (A1, A2 and A3) were used for fish culture. The three tanks are identical in depth (1.0m), but different in size and capacity, which were 19.6, 50.2 and 78.5 m^3 (5.0, 8.0 and 10.0 m diameter), respectively. Each tank was equipped by a particle trap (B1, B2 and B3) set in the concrete tank foundation (floor).

3.1.2. Screen Filter:

Screen filter, driven hydraulically with screen 100 micron is used. The filter dimensions are 1.30m diameter and 1.80m length.

3.1.3. Biological Filter:

A rotating biological contactor (RBC) with used old drip irrigation pipes as a media was used. The filter dimensions are 1.50m diameter and 2.0m length. The details described by Ali et al., 2006.

3.1.4. Oxygen-Water Mixture:

For all of the tanks, one downflow oxygen contactors (H) is used. The mixture has 3.7 m height.

3.1.5. Accessories:

3.1.5.1. Pumps: The system has six centrifugal pumps, $50m^3.h^{-1}$ for each.

3.1.5.2. Oxygen Generator: Airsep type, the discharge is $2m^3$ $O_2.h^{-1}$.

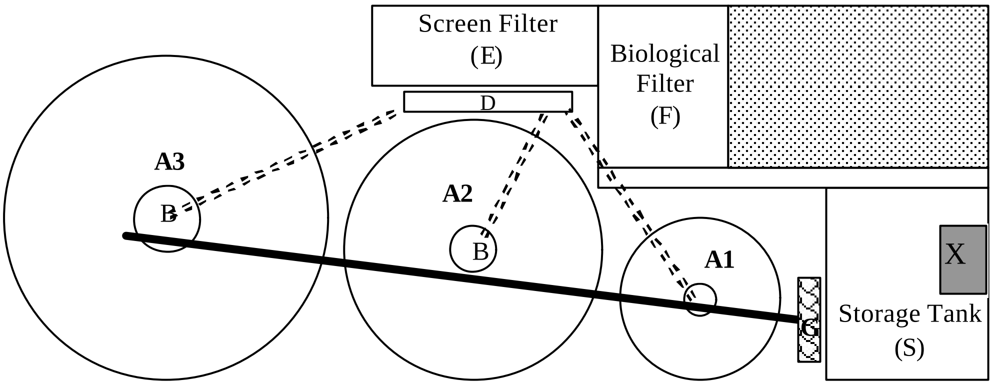

Figure (1). Sketch of the water recycle system. Fish tank, A; particle trap, B; channel collector, D; screen filter, E; biological filter, F; storage tank, S; pumps, G; heat exchanger, X. Arrows indicate the direction of flow.

3.2. Flow Pattern:

A typical growout tank system layout is shown in 'elevation' view in figure (2). Water exits from culture tanks (A1, A2 and A3) through the particle traps (B) to the sludge collectors (C) and a channel collector (D). The water then passes through a drum screen filter (E) to the biofilter (F) to storage tank (S). The water is returned to the culture tanks by centrifugal pumps (G) via downflow oxygen contactors (H), which add pure oxygen to the flow stream. The water re-enters the culture tanks through two vertical manifolds (I) per tank. System piping cross connections provide operational flexibility and heating capabilities via a heat exchanger (X).

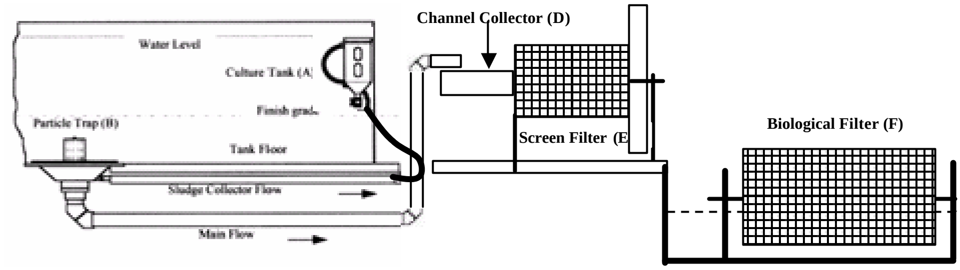

Figure (2): Elevation view of tank system, particle trap, sludge collector, channel collector, drum screen filter and biological filter.

Water flows from the particle trap through two separate pipes to the sludge collector (C) and the channel collector (D) where the flows are rejoined. The flow proceeds through the drum screen filter (E) towards the biological filter. Gravity flow is used as much as possible to carry water through the treatment processes.

Settleable solids are removed rapidly within the culture tank by the particle trap which is shown in detail in figure (3). Settleable solids are captured by the particle trap as they slide beneath a plate located in the tank center just above and parallel to the tank bottom. The uneaten feed and fecal solids are collected in a bowl within the particle trap and are removed via a flow stream designated L in figure (3) were 40, 65 and 100 l min^{-1} in tanks A1, A2 and A3, respectively. The settleable solids that are captured by the particle trap (B) are removed from the flow stream in a 'sludge collector' or settling cone external to the tank as shown in Fig. 4 as flow L. Clarified water overflows from the sludge collector (C) and goes to the adjacent standpipe collector. Flow stream M shown in figure (3) carries suspended solids through the elevated strainer of the particle trap (B) at a design rate of 800,1300 and 2050 l min^{-1} per tank A1, A2 and A3, respectively. The settleable solids and suspended solids flow streams from each tank come together in the channel collector (D) where the flows from all of the tanks combine and are carried to a drum screen filter (E) at a combined rate of 4150 l min^{-1}. At this point, all solids larger than the size of the screen on the drum screen filter are removed by the screen and then by the intermittent high-pressure rinse spray to a waste stream. The filtered water leaves the drum screen filter (E) and exits through the discharge channel which then divides the stream in two flowing to the two 2.5 m diameter biological filter (F) shown in figure (2).

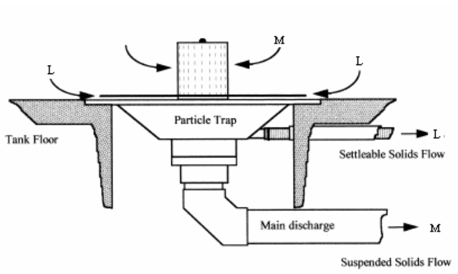

Fig. 3. The particle trap showing high solids: low flow stream L and high flow:low solids stream M.

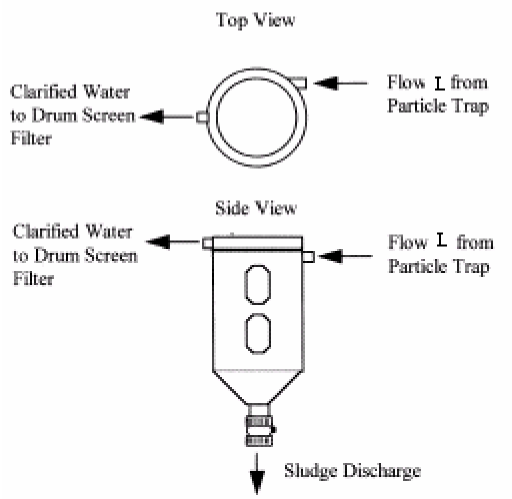

Fig. 4. Sludge collector that works in conjunction with the particle trap to remove settled waste solids from the flow stream (L).

The water passes through plastic biological filter media. The ammonia is converted to nitrate at a (design) rate of approximately 530 g TAN m^{-3} media day^{-1} by the bacteria attached to the media. Water is then pumped from the bottom of storage tank with centrifugal pumps (G) at a rate of 4150 l min^{-1} through oxygen injection components to tanks (Figure 5). Water flowing into the top of the downflow oxygen contactor, is mixed with gaseous oxygen, and exits the bottom in a pressurized (0.5–1.0 bar) flow stream for delivery to the culture tank. The oxygenated water re-enters the culture tank through two vertical manifolds (I) that allow for even distribution of the water from top to bottom in the tank water column.

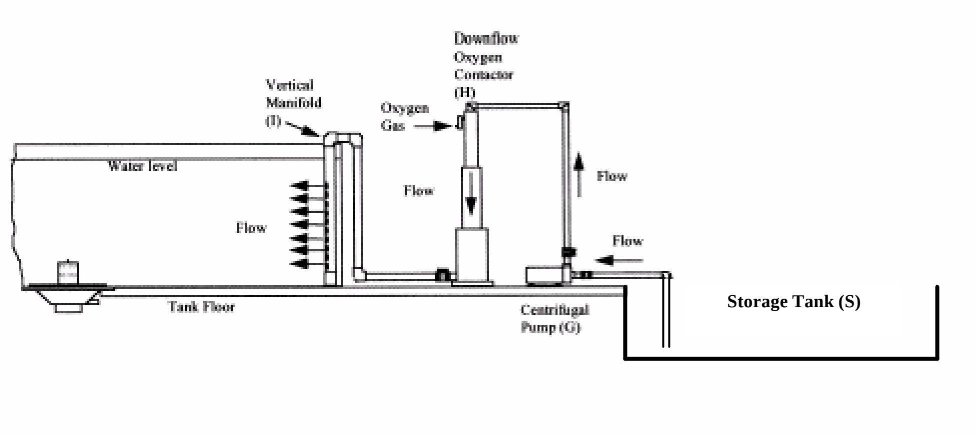

Figure (5): Fish culture tank, downflow oxygen contactor and storage tank.

3.3. Water Characteristics:

Water used throughout experimentation was derived from well. Total ammonia nitrogen (TAN) and nitrite were below the limits of detection. Dissolved oxygen was 1.5 mg/L. The pH was 7.5.

3.4. Experimental animals

Tilapia nilotica fingerlings were used. The fish was weighed every 2 weeks; the flow rate of water and oxygen discharge was adjusted accordingly.

3.5. Sampling and Measurements

Water samples were taken for measuring unionized ammonia nitrogen (NH_3), nitrite and nitrate. Dissolved oxygen, temperature and pH were measured directly in the field.

Unionized ammonia (NH_3), nitrite and nitrate were measured by an ion selective electrode (ORION 710). Dissolved oxygen was measured by a digital oxygen analyzer (ORION 810), provided with a dissolved oxygen prop (No. 81010). The pH was measured by the pH meter (ORION 230A), provided with pH electrodes (No. 910500).

3.6. Calculated Parameters.

To estimate the growth rate and feed conversion ratio (FCR), 10 fish were weighed every 2weeks. At the end of the production period all the fish were harvested and weighed.

Daily growth rate (DGR), expressed as (g/day), was calculated by the formula:

DGR = (final weight - initial weight) / time (days)

Feed conversion ratio (FCR) was calculated by the formula:

FCR = Amount of dry feed (kg_{feed} /day) /DWG (kg_{fish}/day)

Net yield (NY), expressed as g/m^3 day, was calculated by the formula:

NY = (final biomass / m^3 - initial biomass / m^3)/time (days)

3.7. Operational Planned Sequence.

Up to 10% of the water volume of the system is exchanged each day (that is, 10% new water enters, while 90% is filtered and reused). Incoming fingerlings are initially stocked into 20 m^3 (A1) tank, where they are held for 8 weeks. They are then harvested and restocked into the 50 m^3 (A2) tank. After another 8 weeks of growth the fish are transferred to 75 m^3 A3 tank. There, the fish remain for another 50-60 days, and then they are harvested. Thus, the total cycle time between first stocking and first harvest is about 180 days. One tank is harvested per 2 months. Fish are moved from tank to tank to make optimum use of the production capacity of the system. As the tilapia grow and require a larger water volume, they are transferred into larger tanks. When the preceding tank is unoccupied, another group of fish called a cohort is introduced into the system. As a result, once the system is fully stocked, A3 tank will be harvested every 50 to 60 days, resulting in a constant, year-round supply of tilapia. The biological filters were allowed to populate naturally with nitrifying bacteria. This is typical of tank systems that share water treatment components and of those that are harvested numerous times to satisfy local markets.

In feeding the fish, the recommendations of feeding rates for different size groups of tilapia in tanks of Rakocy, 1989 and, the recommendations of Jauncey and Ross, 1982 for the feed pellets diameter was used.

3.8. Economical Evaluation.

An Excel program which was developed by Dunning et al. (1998) was used to estimate initial investment, operating costs, and annual returns for a three tanks facility. Production costs and sale price are based on the experiences over the past 3 years at El-Nenaeia fish farm.

The spreadsheet is divided into five sections. The user supplies information for the first three sections. Data in the final two sections are calculated from these information.

3.8.1. Initial Investment.

The initial investment (Table 1) includes the total value of a settling pond, building, equipment, and construction labor, as well as the current value of any owned assets used in the business. Annual depreciation on building and equipment is the amount of money that must be earned each year by the business to eventually replace equipment when it wears out. Interest rate on operating capital is used to calculate a cost of interest on variable inputs (energy, bicarbonate, fingerlings, chemicals, maintenance and labor). Interest rate on building and equipment is used to calculate an annual interest charge based on the average investment. It is to be mentioned that, these parameters are calculated in tables (5 and 6) as set in the program.

Table (1): Summary of Initial Investment

Initial investment		Units
Settling pond	5,000.00	L.E.
Equipment	200,000.00	L.E.
Building	50,000.00	L.E.
Construction labor & overhead	25,000.00	L.E.
Total initial investment	280,000.00	L.E.
Annual depreciation on bldg. & equip.	33,904.76	L.E.
Interest rate on operating capital	9%	
Interest rate on bldg. & equip.	10%	

3.8.2. Operating Costs and Returns (Table 2).

- Variable costs

Variable costs are those directly related to production; energy, bicarbonate, fingerlings, chemicals, maintenance and labor.

- Fixed costs

Fixed costs are incurred regardless of whether or not production occurs. They are Land rental, Electrical demand charge and Building overhead. Each of these is specified as a cost per month.

- Sale price

Average overall sale price is the weighted average sale price per kg, taking into account the size distribution at harvest and differing prices for various sizes of fish. In this analysis L.E.9.0 is uses.

- System parameters

Annual production: Average size at harvest and the Survival rate are used to calculate the initial stocking density. This is considered for each tank.

Water volume (m^3): used to calculate the maximum standing biomass, kg m^{-3} of water for any tank; Size stocked is the average size of fish stocked into that production unit.

Size harvested: the average size when transferred or harvested from the system. In the current trial, fish are initially stocked at 5 gram into the A1 tank, and transferred into the A2 tank when they reach 35 grams.

Survival rate: the percentage of survival for that production unit.

Feed cost per kg: the average cost per kg for feed fed to that production unit. Feed cost, per kg and Feed conversion are used to calculate the cost of feed for each production unit, for each cycle, and annually. Feed usage is also used to calculate the amount of energy used.

Table (2): Operating Costs and Returns.

Item	Unit or description	cost
Variable Costs:		
Energy	L.E./kW.h	0.18
Bicarbonate	L.E./kg	1.00
Fingerlings	L.E./fingerling	0.09
Chemicals	L.E/cycle	300.00
Maintenance	L.E./month	250.00
Labor: management	L.E./month	1,500.00
Labor: transfer & harvest	L.E./hour	4.00
Fixed Costs:		
Land rental	L.E./month	60.00
Electrical demand charge	L.E./month	250.00
Building overhead	L.E./month	200.00
Average overall sale price	L.E./kg	9.00
System Parameters		
Annual production	kg	30,000
Average size at harvest	kg	0.25
Number of production units	number	3
Days per production unit	days	60
kW.h per kg of production	kW.h/ kg prod.	5.00
System volts	volts	230
Transfer/harvest labor	hrs per cycle	32

Tank	A1	A2	A3
Water volume, m^3	20.00	50.00	75.00
Size stocked (grams)	5	35	120
Size harvested (grams)	35	120	250
Survival rate	85%	95%	95%
Feed cost, L.E./kg	3.40	2.40	1.90
Feed conversion	1.10	1.20	1.40

5. SYSTEM RESULTS

5.1. Physical Results.

5.1.1. General Performance of System.

The readings indicate that the dissolved oxygen concentration was found to be in range from 6–9 mg.l^{-1}. Lowest oxygen concentrations were experienced in the late afternoon after a prolonged period of feeding. Depending upon feed delivery adjustments, feed was supplied for 8–10 h per day, every 2 hours.

The water quality and associated feed rate data for the system for the 11 week sampling period are presented in Figs. 7 and 8. Unionized ammonia concentration ranged from 0.0093 to 0.012 mg l^{1} with an average of 0.011 mg l^{-1}±0.0012 over the period between 9 January and 1 April 2006. The pH within the system ranged from 6.7 to 7.7. Nitrite–nitrogen concentration over the same period varied from 0.05 to 0.62 mg l^{1} with an average concentration of 0.23 mg l^{-1} ±0.19. Nitrate–nitrogen concentration over the same period varied from 0.41 to 18.94 mg l^{1} with an average concentration of 3.86 mg l^{1} ±5.76. These results indicated that water quality in the fish tank remained excellent of tilapia production according to **Boyd (1982), Lawson (1995) and Soderberg (1995)** during the study.

5.1.2. Fish Growth Rate.

Table (3) shows that number of fish, mean weight (MW) of individual fish (g), stocking density (SD) (kg.m^{-3}) and feed quantity (FQ) (kg.day^{-1}) during the production period (weeks). Tank A1 was stocked on 1 October 2005 with 23000–5.0 g (average weight) tilapia fingerlings (*Oreochromis niloticus*). The biofilter were injected with nitrifying bacteria. After 8 weeks of growth the fish were transferred to tank A2 with 21100-34.1 g. After another 8 weeks of growth the fish were transferred to tank A3 with 20300-114.4 g. Tank A1 was restocked on 6 December 2005 with 25000–5.5 g.

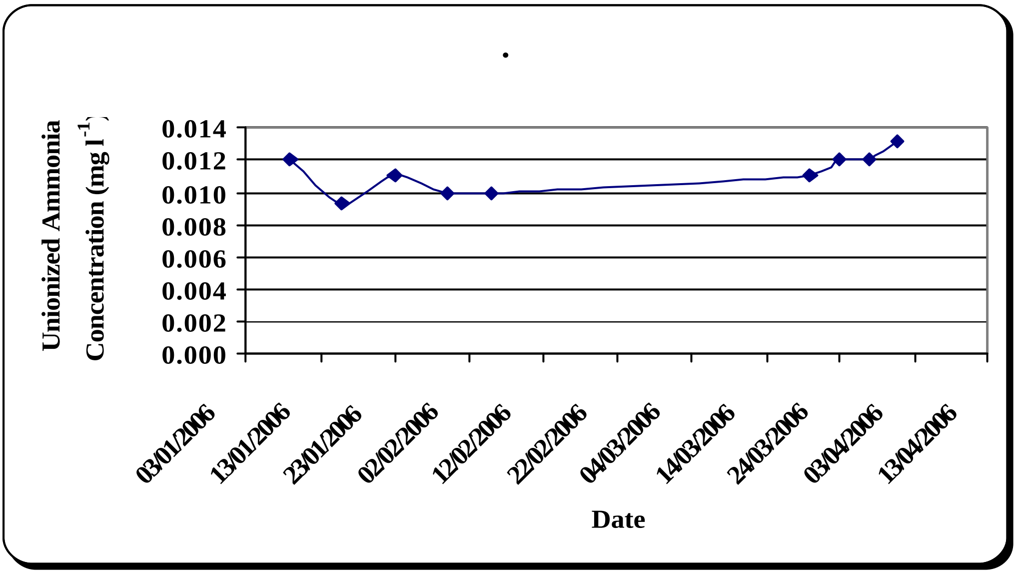

Figure (7): Measured unionized ammonia concentration in the system during a 11 week period.

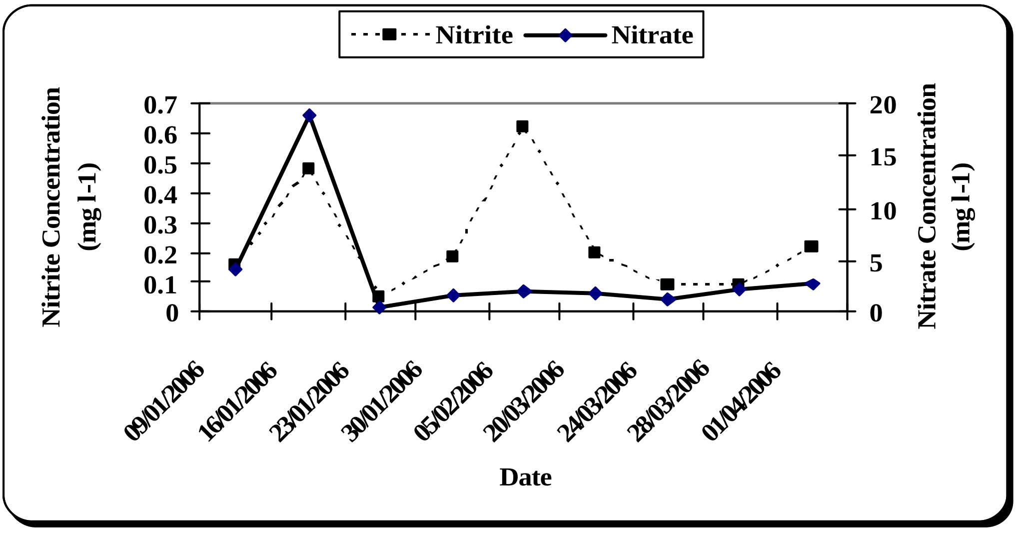

Figure (8): Measured nitrite-nitrogen and nitrate-nitrogen concentration in the system during a 11 week period.

Table (3) Number of fish (Thousand), mean weight (MW) of individual fish (g), stocking density (SD) (kg/m^3) and feed quantity (FQ) ($kg\ day^{-1}$) during the production period (weeks).

Wee	Tank A1 ($20m^3$)				Tank A2 ($50m^3$)				Tank A3 ($75m^3$)			
	No.	**MW**	**SD**	**FQ**	**No.**	**MW**	**SD**	**FQ**	**No.**	**MW**	**SD**	**FQ**
1	**23.0**	**5.0**	**5.75**	**6.0**								
3	**22.1**	**8.9**	**9.80**	**8.5**								
5	**21.7**	**14.9**	**16.1**	**13.1**								
7	**21.4**	**23.2**	**24.8**	**19.3**								
Transferred												
9					**21.1**	**34.1**	**14.3**	**25.0**				
11					**20.8**	**48.0**	**19.9**	**31.0**				
13					**20.6**	**65.3**	**26.9**	**41.0**				
15					**20.5**	**86.3**	**35.4**	**50.0**				
Transferred												
17									**20.3**	**111.4**	**30.1**	**63**
19									**20.2**	**141.0**	**37.9**	**74**
21									**20.1**	**175.3**	**46.9**	**92**
23									**20.05**	**214.0**	**57.2**	**105**

Table (4) shows the daily weight gain ($g\ day^{-1}$), the feed conversion ratio and the net yield for both the first and the second experiments.

Table (4): Daily weight gain ($g\ day^{-1}$), the feed conversion ratio and the net yield ($g\ m^{-3}.day^{-1}$) for both the first and the second experiments

Items	
Daily Weight Gain (DWG), ($g.day^{-1}$)	1.56 ± 0.96
Feed Conversion Ratio (FCR)	1.39 ± 0.16
Net Yield, ($g\ m^{-3}.day^{-1}$)	392

The daily weight gain ranged from 0.25 to 3.5 (mean 1.56±0.96 $g\ day^{-1}$). The feed conversion ratio (FCR) ranged from 1.13 to 3.50 (mean 1.39 ±0.16). The net yield (NY) ranged from 253.51 to 463.17, (mean 392.16 $g\ m^{-3}.day^{-1}$). All these trends point to the fact that the overall growth rate of tilapia in the present recirculation system was slightly high, compared with results obtained by Suresh and Lin. 1992.

5.1. Economical Results.

Data in tables (1, 2) are calculated from the information were presented in tables (5, 6).

Table (5): Inputs and costs per production unit.

Inventory & Input Use:	A1	A2	A3	Cycle Total	Annual Total
Beginning number of fish	25,714	21,857	20,764	25,714	156,428
Ending number of fish	21,857	20,764	19,726	19,726	120,000
Beginning biomass, kgs of fish	129	765	2,492	129	782
Ending biomass, kgs of fish	765	2,492	4,932	4,932	30,000
Maximum standing biomass, kg/m³ of water	38.25	49.83	65.75	---	---
Feed used, kg	700	2,072	3,416	6,188	37,643
kW.h used	2,790	8,257	13,611	24,658	150,000
Oxygen used, m³	72	212	350	633	3,853
Bicarbonate used, kg	55	164	271	490	2,981
Costs (L.E.):					
Fingerlings	2,314.28			2,314.28	14,078.54
Feed	2,380.24	4,972.93	6,489.86	13,843.03	84,211.75
Energy	502.14	1,486.22	2,449.99	4,438.36	27,000.00
Bicarbonate	0.00	0.00	0.00	0.00	0.00
Total of above costs for this production unit	55.45	164.11	270.54	490.10	2,981.44
Cumulative cost for cycle	5,252.11	6,623.26	9,210.39	21,085.76	128,271.72
Cumulative cost per kg	5,252.11	11,875.37	21,085.76	21,085.76	128,271.72

Table (6): Summary of Annual Costs & Returns to System in Full Production

Days per production unit =	**60**	**Overall survival**	**77%**
Number of cycles per year =	**6.08**	**Cycle FCR**	**1.3**
Req. system amps	**74**		

	unit	cost/unit	Quantity per cycle	L.E./cycle	L.E./year	L.E./ kg of fish	% of total
Gross Receipts	**kg**	**9.00**	**4931.51**	**44383.56**	**270000.00**	**9.00**	
Variable Cost (L.E.)							
Fingerlings	unit	**0.09**	**25,714.23**	**2,314.28**	**14,078.54**	**0.47**	**7%**
Feed	kg	**2.24**	**6,187.84**	**13,843.03**	**84,211.75**	**2.80**	**40%**
Energy	kWh	**0.18**	**24,657.53**	**4,438.36**	**27,000.00**	**0.90**	**13%**
Bicarbonate	kg	**1.00**	**500.24**	**500.24**	**3,043.14**	**0.10**	**1%**
Chemicals	L.E. per cycle	**591.78**	**1.00**	**591.78**	**3,600.00**	**0.12**	**2%**
Maintenance	L.E. per cycle	**493.15**	**1.00**	**493.15**	**3,000.00**	**0.10**	**1%**
Labor: management	L.E. per cycle	**2,958.90**	**1.00**	**2,958.90**	**18,000.00**	**0.60**	**9%**
Labor: transfer & harvest	hour	**4.00**	**32.00**	**128.00**	**778.67**	**0.03**	**0%**
Interest on variable costs		**0.09**	**13,698.21**	**607.98**	**3,698.52**	**0.12**	**2%**
Subtotal, Variable Cost				**25,861.55**	**157,324.43**	**5.24**	**75%**
Fixed Cost							
Land rental				**118.36**	**720.00**	**0.02**	**0%**
Electrical demand charge				**493.15**	**3,000.00**	**0.10**	**1%**
Building overhead				**394.52**	**2,400.00**	**0.08**	**1%**
Interest on bldg. & equip.				**2,054.79**	**12,500.00**	**0.42**	**6%**
Depreciation on bldg. & equip.				**5,573.39**	**33,904.76**	**1.13**	**16%**
Subtotal, Fixed Cost				**8,634.21**	**52,524.76**	**1.75**	**25%**
Total Costs				**34,495.76**	**209,849.19**	**6.99**	**100%**
Returns above Variable Costs				**18,522.01**	**112,675.57**	**3.76**	
Returns above Total Costs				**9,887.80**	**60,150.81**	**2.01**	

From table (6) the total cost per kg produced, per cycle and per year were 6.99, 34495 and 209849 L.E., respectively. Returns above variable costs were 3.76, 18522 and 122675 L.E. and above total costs were 2.01, 9887 and 60150 L.E. for the functions, respectively. These results show the economical reusability of the system.

6. CONCLUSIONS

El-Nenaeia Fish project at Menofia Governorate provides a unique opportunity to collect and analyze data from a recirculating fish production system at the commercial scale. This manuscript provides a detailed review of the main growout system technology within the facility and an examination of preliminary data collected at the facility.

The data from operation of the system indicate that the actual operational characteristics of the system approached the design goals of the tank growout system. In most cases variances from the design rates were caused by reduced amounts of feed input to the system. The reduced average feed rate was caused by fluctuations in the system biomass as a result of multiple harvests during this study. Increased new water usage occurred early in the study as a result of startup activities and the multiple harvests. Subsequent water use has approached or equaled the design rate. This type of system could be one of the solutions for fish farming in Egypt.

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