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DESIGN OF A ROTATING BIOLOGICAL CONTACTOR IN A RECIRCULATING AQUACULTURE SYSTEM

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ABSTRACT

This paper describes a design of an industrial-scale rotating biological contactor (RBC) and its performance installed in recirculating aquaculture system culturing tilapia at El-Nenaeia Fish Farm which was described by Ali et al., 2006. The total surface area provided by the RBC equaled 2352 m^2. Ammonia removal efficiency averaged 33.2%, equated to an average (± standard deviation) total ammonia nitrogen (TAN) volumetric loading and removal rate of 368.9±126.2 and 133.3±68.8 g TAN.m^{-3}.day^{-1}, respectively.

Keywords: Biofiltration; Rotating biological contactor; Aquaculture; Recirculating aquaculture system; Nitrification.

INTRODUCTION

Water quality maintenance in recirculating aquaculture systems (RAS) is focused on the detoxification of nitrogenous wastes, oxygenation, removal of suspended solids, and controlling the accumulation of organic compounds. Once the system's oxygen requirement, which includes that needed for fish respiration and microbial processes, is met, nitrogenous wastes, primarily ammonia, become the next important limiting factors (Lawson, 1995). Ammonia accumulation in recirculating systems is controlled through water exchange and biofiltration.

Biofilters are an integral part of recirculating aquaculture systems (Libey and Miller, 1985; Wheaton et al., 1991) and maintain chemoautrophic bacteria,

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including those that oxidize ammonia to nitrate in a two-step process known as nitrification. Excess unionized ammonia (as NH3-N) concentration can detrimentally effect fish growth and health, and ultimately lead to mortality (Colt and Armstrong, 1981).

Mortality results from gill hyperplasia (Colt and Armstrong, 1981), a condition which decreases gill surface area and thereby leads to inadequate transfer of toxic metabolites from the fish to the culture water. Although acute ammonia toxicity values vary between fish species (Rogers and Klemetson, 1985). Colt and Armstrong (1981) reported that most aquatic organisms experience significant growth reductions at concentrations between 0.05-0.20 mg l^{-1}. Because fish growth rate is a significant profit-determining factor in production aquaculture, ammonia concentrations must be maintained consistently below toxic levels.

Nitrification biochemically oxidizes total ammonia ($NH4^+$-N and NH3-N) to nitrate, allowing culture water to be recycled many times prior to discharge from the system. Recycling reduces the volume of effluent discharged on a day-to-day basis. Although nitrification has been found to exist throughout the culture system (Rogers and Klemetson, 1985; Losordo, 1991), high levels of sustained nitrification could not be attained without use of a biofilter.

Mechanical filtration also must be employed to ensure consistent removal of particulate matter and organic wastes. Organic degradation within the culture environment can significantly deteriorate system water quality and increase biofilter clogging (Lucchetti and Gray, 1988). The majority of organic wastes stem from uneaten feed, sloughed biofilm, and fecal matter (Libey, 1993; Piedrahita et al., 1996).

Biofilter types range from submerged bead and fluidized sand bed reactors to trickling filters, rotating biological contactors and rotating drums. Several of these designs are suitable for use in production aquaculture (Miller and Libey, 1985; Rogers and Klemetson, 1985; Malone et al., 1993; Honeyfield and Watten, 1996; Summerfelt, 1996; Westerman et al., 1996). However, no configuration has been found best suited for treatment of aquaculture effluents. This raises the question of which configuration expresses the greatest number of positive attributes regarding treatment effectiveness, filter operational characteristics and filter management needs when confronted with waste loading conditions normally encountered in production aquaculture.

Several studies have described the performance of fluidized bed filters (Sandu et al., 2002; Summerfelt and Sharrer, 2004), trickling filters (Kamstra et al., 1998), and microbead filters (Greiner and Timmons, 1998) from large production scale systems but there has been little information on the performance of rotating biological contactor (RBC) systems in commercial aquaculture operations.

The term RBC generally defines a class of the fixed film biologic filters where the media is attached to a central horizontal shaft that is rotated to temporarily submerge a portion of the media in the water. The concept was first developed in 1900 for biologically treating domestic wastewater (Hynek and Chou, 1979). However, commercial development, research, and installation were not seen until the 1970s in Germany and the United States (Wheaton et al., 1994). During this time, the development of media with high specific surface area increased removal rates and helped reduce costs (Hynek and Chou, 1979).

RBC is typically constructed of plastic media or molded sections that are closely spaced to provide a relatively large total surface area within a relatively small space, but far enough apart so that the filter does not clog from biological growth and bridging. Excess biofilm growth is mechanically sheared as the media surface rotates through the water. RBC shafts can be positioned parallel or perpendicular to the water flow. Rotation of the shaft can be controlled by a shaft drive motor (Ayoub and Saikaly, 2004), an airlift system (Hynek and Chou, 1979), or water jet (Van Gorder and Jug-Dujakovic, 2004).

This paper describes a design of an industrial-scale rotating biological contactor (RBC) and its performance installed in recirculating aquaculture system culturing tilapia at El-Nenaeia Fish Farm which was described by Ali et al., 2006.

MATERIALS AND METHODS.

1. Design Objectives.

The intended design of RBC is to serve a commercial recirculating aquaculture system, which was described by Ali et al., 2006 (Figure 1). Water exiting the culture tanks A1, A2 and A3 (145 m^3) flowed through a screen filter (E) and was then directed through two industrial scale RBC unit. The treated water was then pumped down flow oxygenation system before reentering the culture tank. Each RBC unit was constructed and positioned with the central axis perpendicular to the treatment flow (Figure 2). The two filters were equally sized (1.5m diameter, 2.0m long). The RBC was operated at 40% submergence and rotated at approximately 3 rpm (peripheral velocity of 0.23 m s^{-1}). An old drip irrigation pipes is used as a media.

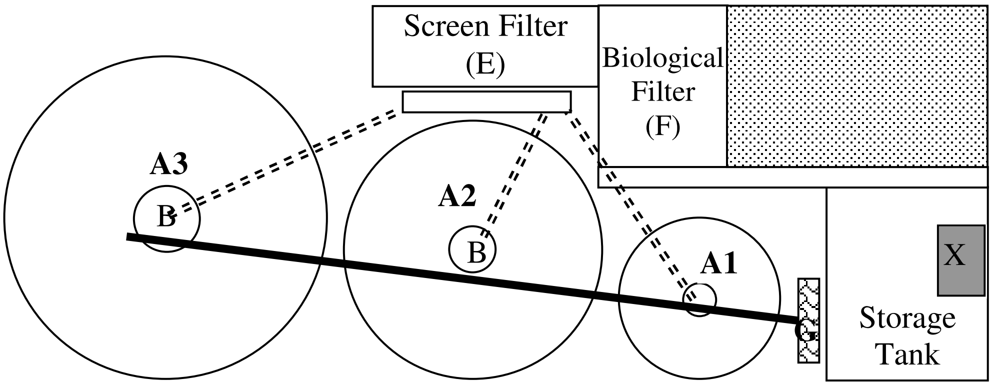

Figure (1). Sketch of the water recycle system. Fish tank, A; particle trap, B; channel collector, D; screen filter, E; biological filter, F; storage tank, S; pumps, G; heat exchanger, X.

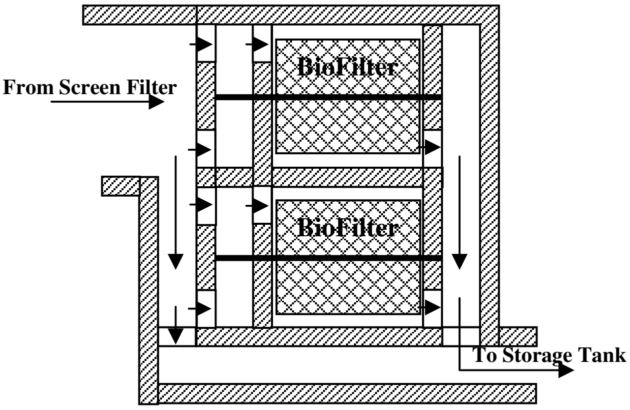

Figure (2): Layout of rotating biological contactor (RBC) filter.

2. Biological Filter Design and Manufacture.

2.1. Design Steps.

The sizing of a biofilter can be divided into the following ten steps:

1. Determine system water volume (Vs).
2. Determine the maximum fish load: The fish load, L = (Water Volume (m^3)) (Final Fish Density (kg m^{-3})).
3. Determine the maximum daily feed input: Given by recommendations of Rakocy, 1989 as f of body weight per day : F = (f)(Maximum fish load).
4. Establish the feed protein content (%).
5. Establish the system operating temperature: Given by Literatures as T =28°C.
6. Establish system operating salinity: Given by Literatures as 0 ppt.
7. Select a value or method for calculating TAN produced per kilogram of feed: E_{TAN} = 30 g TAN kg^{-1} feed at 35% protein to support warmwater fish (Malone et al., 1990; Wimberly, 1990).
8. Select a correction factor for feed protein if protein content deviates from 35%. Since the protein content of the feed being used by the customer is 40%, TAN excretion can be estimated by: E_{TAN} = P2(30 g TAN kg^{-1} feed)/(35%protein) where P2 is the protein content of the new feed (in this case, 40%) and the ratio of 30/35 is determined from step 7 above (Malone and Beecher, 2000).
9. Calculate the total daily TAN production (kg day^{-1}) (Malone and Beecher, 2000): TAN_T = (1- Is) E_{TAN} (Maximum daily feed input). Is = 30% (Mia, 1996).
10. Using measured volumetric TAN conversion rate (VTR) values for the filter and/or filter media being compared, determine the volume, V_b (m^3) of the filter required to provide the targeted water quality conditions. Using enhanced nitrification media (EN) a VTR of 530 g TAN m^{-3} media day^{-1} is readily achievable.

Table (1) illustrates the farm characteristics which used the intended design of the biological filter will serve.

Table (1): Given farm characteristics.

Characteristic	Tank (A1)	Tank (A2)	Tank (A3)
Water Volume (m^3)	20	50	75
Final Fish Density (kg m^{-3})	35	120	250
Feed Protein Content (%)	40%	30%	25%
Number of Fish per Tank	20,000		
TAN produced per kilogram of feed	30 g TAN kg^{-1} feed at 35% protein		
Volumetric TAN conversion rate(VTR)	530 g TAN m^{-3} media day^{-1}		

Operating the previous steps using the design parameters of table (1), table (2) shows the results upon which the filter was manufactured.

Table (2): The design results of biological filter.

Parameter	Tank (A1)	Tank (A2)	Tank (A3)
Maximum Fish Load (kg)	700	2400	5000
Maximum Daily Feed Input (kg)	25	65	125
Daily TAN Production (kg day^{-1})/ Tank	857	1671	2678
Total Daily TAN Production (kg day^{-1})	5206		
TAN_T	3644.2		
Volume of the filter required (m^3)	6.8 m^3		
Number of units	2		
Volume of the filter designed (m^3)/ unit	2 X 3.5 m^3		
Rotating Speed, m s^{-1} (rpm)	0.23 (3.0)		

2.2.2. Biological Filter Manufacture.

The two units of RBC were manufactured from stainless steel at private company for steel industry. Used drip irrigation pipes were used as a media after cutting to small pieces (1-2cm length). The two units were driven by one motor of 1.5 kW power and 1500 rpm and a gearbox of reduction ratio of 500 to give the recommended rotating speed (3 rpm).

3. Sample collection and analysis

Water samples were collected from the inlet and outlet of RBC at intervals equivalent to the retention time and used to characterize the nitrification kinetic performance.

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).

4. Feed Management.

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.

RESULTS AND DISCUSSION

1. General Performance.

The water quality data for the system for the 20 weeks sampling period are presented in figure (3). Unionized ammonia concentration ranged from 0.0093 to 0.018 mg l^{-1} with an average of 0.0131 mg l^{-1}±0.0027 and from 0.005 to 0.0135 mg l^{-1} with an average of 0.0083 mg l^{-1}±0.0027 over the period between 9 January and 4 May 2006 before and after the RBC, respectively. 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 of 0.26 mg l^{-1}±0.19 and from 0.03 to 0.46 mg l^{-1} with an average of 0.18 mg l^{-1}±0.15 before and after the RBC, respectively. Nitrate–nitrogen concentration over the same period varied from 0.409 to 18.94 mg l^{-1} with an average of 4.0 mg l^{-1} ±4.56 and from 1.39 to 34.93 mg l^{-1} with an average of 8.4 mg l^{-1}±8.4 before and after the RBC, respectively. 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.

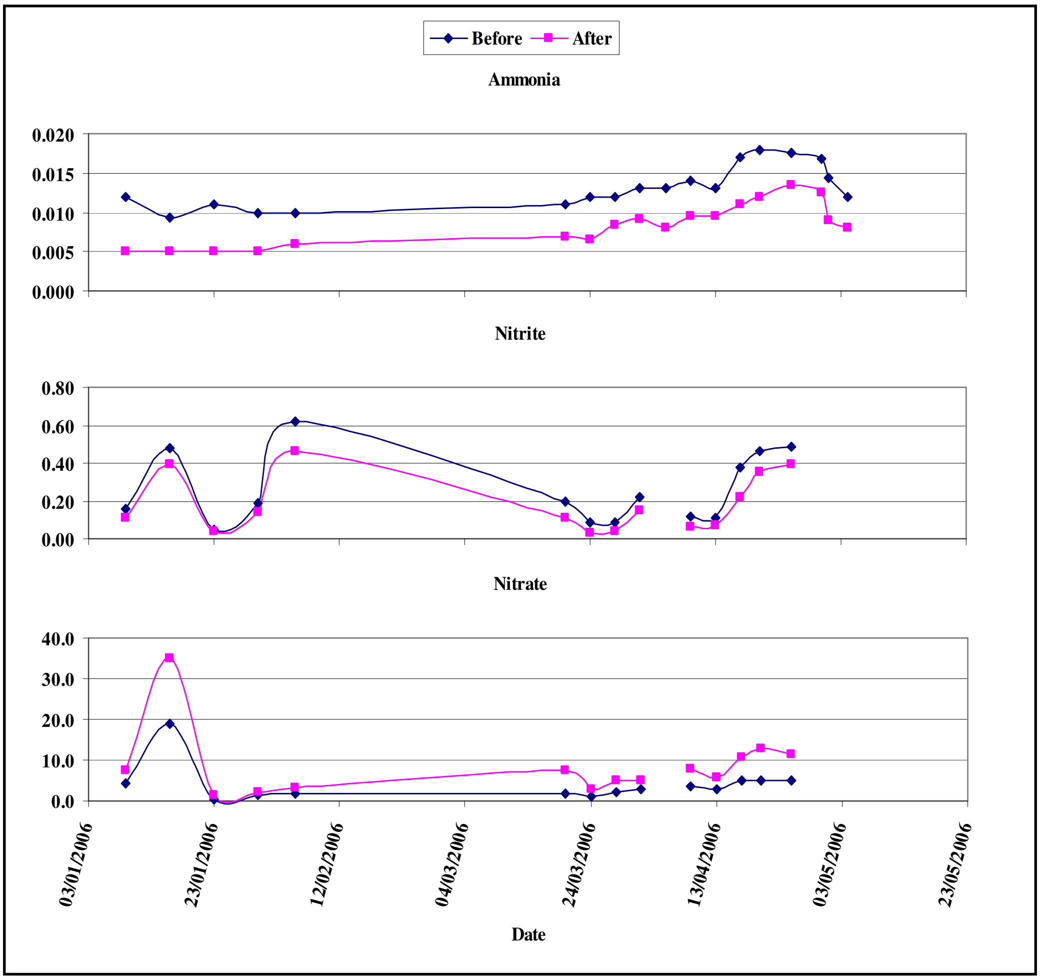

Figure (3): Unionized ammonia, nitrite and nitrate concentration (mg.l^{-1}) for 20 weeks period before and after the RBC.

2. Ammonia oxidation performance

Ammonia removal efficiency was relatively linear as influent TAN concentration approached 3.75 mg.l^{-1} before becoming asymptotic at approximately 40% removal efficiency as described by the solid trend line (Fig. 4). Figure (5) shows that, the mass ammonia removal rate (ARR) was increased linearly with increasing ammonia loading rate (ALR). The RBC achieved an averaged volume ammonia loading and removal rate of 368.9±126.2 and 133.3±68.8 g TAN.m^{-3}.day^{-1}, respectively.

Multiple regression was carried out for the ammonia removal rate data as influenced by ammonia loading rate. The following equations were the best fit for the data:

$$ARR = 0.5338\ ALR - 63.645 \qquad (R^2=0.957)$$

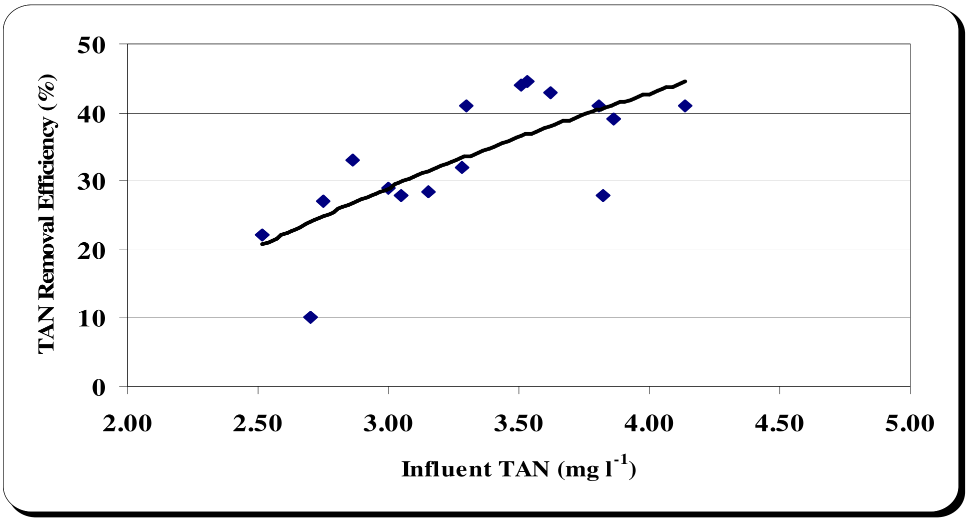

Figure (4): Effect of influent TAN (mg l^{-1}) on TAN removal efficiency (%).

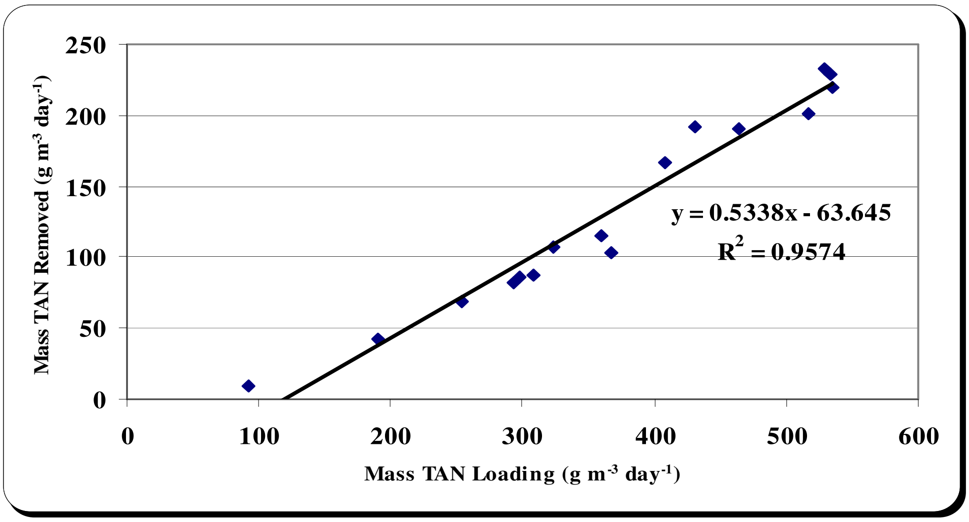

Figure (5): Effect of mass loading ($g.m^{-3}.day^{-1}$) on mass TAN removal ($g.m^{-3}$ day^{-1}).

CONCLUSIONS

The rotating biological contactor (RBC) is the optimal type of biofilters used for aquaculture recirculating system. RBC design criteria were identified and operated to give design parameters. The RBC was manufactured locally from stainless steel and media from used polyethylene (PE) pipes. The performance of the designed RBC proves to be adequate for the farm.

An average loading and removal rate were 368.96±126.20 and 133.3±68.85 g TAN.m^{-3}.day^{-1}, respectively was achieved. Increases in ammonia concentrations improved removal efficiency up to an ammonia concentration of 3.75 mg.l^{-1}, beyond which removal efficiency remained about 40%.

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تصميم مرشح حيوى من النوع الدوار فى نظام لإعادة تدوير المياه فى الزراعة المائية

سمير أحمد على، زكريا الحداد* أحمد غريب**

تعتبر عملية الترشيح الحيوى من أهم العمليات فى الاستزراع المائى، للتخلص بصفة مستمرة من نواتج العمليات الحيوية للأسماك، حيث تخرج على شكل غاز الأمونيا وهي المظهر الذي تخرج عليه فضلات النيتروجين من الأسماك عن طريق خياشيم الأسماك كنتيجة لعملية التمثيل الغذائي كما يتصاعد غاز الأمونيا في المياه أيضا كنتيجة لتحلل المخلفات العضوية للأسماك وبقايا الغذاء غير المأكول المتراكم في القاع. وتوجد الأمونيا في المياه بأحد الشكلين إما متأينة NH_4^+ أو غير متأينة NH_3 ويطلق على مجموع الشكلين المتأين وغير المتأين الأمونيا الكلية. ونسبة الأمونيا الغير متأينة من الأمونيا الكلية تتوقف على كل من درجة الحرارة والرقم الهيدروجيني pH. وبشكل أقل درجة ملوحة المياه والشكل غير المتأين NH_3 يزداد تركيزه في المياه بزيادة الرقم الهيدروجيني pH وزيادة درجة الحرارة. الأمونيا الكلية عادة سامة للأسماك ولكن الشكل غير المتأين سامة جداً ومما هو جدير بالذكر أن مستوى الأمونيا الغير متأينة يجب ألا يزيد عن ٠,٠٢٥ مجم/لتر. ارتفاع التركيز عن ٠,٠٦ مجم في اللتر يبطئ من سرعة نمو الأسماك بشكل ملحوظ والتركيزات الأعلى من ٠,٢ مجم في اللتر تسبب نفوق الأسماك.

والمرشحات الحيوية هى التى تقوم بهذه العملية عن طريق أكسدة الأمونيا إلى نيتريت ثم إلى نترات عن طريق بكتريا الــ Nitrosomonas و الــ Nitrobacter على الترتيب. ومن ثم كان الهدف من هذه الدراسة هو تصميم وتشغيل أحد أهم المرشحات الحيوية وهو المرشح الحيوى الدوار. حيث تم تصميم مرشح حيوى لمزرعة سمكية مكثفة الذى سبق وصفها فى الدراسة التى قام بها على وآخرون (٢٠٠٦)، وكانت أهم نتائج الدراسة مايلى:

- متوسط كفاءة إزالة الأمونيا ٣٣,٢%.
- معدل تحميل و إزالة الأمونيا ٣٦٨,٩٦±١٢٦,٢٠ و ١٣٣,٣±٦٨,٨جرام أمونيا لكل م^{٣} من حجم بيئة المرشح الحيوى فى اليوم، على الترتيب.

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