Aquacultural Engineering 4 (1985) 135–154

Ammonia Removal in Selected Aquaculture Water Reuse Biofilters

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ABSTRACT

Four fixed-film biological filters (rotating biological contactor, biodrum, trickling filter, and a submerged anaerobic filter) were tested for the removal of ammonia using a simulated warmwater fish and invertebrate culture water supply. Filter design may be determined based on the results of ammonia removal efficiency over a wide range of hydraulic loads. The rotating biological contactor (RBC) provided the best ammonia removal (over 90%) up to about $0{\cdot}06\ m^3\ m^{-2}\ day^{-1}$ *(*$1{\cdot}2\ gpd\ ft^{-2}$*). The biodrum removed over 80% of the ammonia to a hydraulic load of* $0{\cdot}05\ m^3\ m^{-2}\ day^{-1}$ *(*$0{\cdot}9\ gpd\ ft^{-2}$*). The trickling filter removed 50% of the ammonia at a hydraulic loading of* $0{\cdot}012\ m^3\ m^{-2}\ day^{-1}$ *(*$0{\cdot}3\ gpd\ ft^{-2}$*).*

INTRODUCTION

Interest in the commercial culture of warmwater aquatic animals is steadily moving in the direction of industrialization. This progress is demonstrated in the advances in extensive fish farming resulting from controlled application of feed and fertilizer, careful water quality monitoring, disease prevention and therapeutic treatment, as well as controlled aeration of ponds and raceways (Bardach, 1976). Limitation to further intensification is posed by the accumulation of toxic inorganic and organic compounds in the water.

Aquacultural Engineering 0144-8609/85/$03.30 –

Table 1 presents water quality criteria that should be considered in evaluating a water supply for aquaculture development. The suggested level for each parameter is based on evaluation of water quality levels listed in five publications (Nightingale, 1976; US EPA, 1976; Roberts, 1978; Environment Canada, 1979; Klontz *et al.*, 1979). The most critical parameters for aquaculture development are ammonia, carbon dioxide, dissolved oxygen, nitrite, pH, temperature and heavy metals. Continual monitoring of those critical parameters throughout operation of the fish culture facility would be costly. As a result, water quality monitoring during production has, in most extensive culture facilities, been limited to routine analysis of pH, dissolved oxygen and suspended solids. In recirculating intensive culture systems, many additional water quality parameters need to be evaluated since productivity and mortality would be adversely affected by unacceptable levels of toxic organic and inorganic compounds in the aquatic environment.

The present study considered four biological fixed-film processes (rotating biological contactor, biodrum, trickling filter and submerged filter) to evaluate suitability for aquaculture wastewater treatment. The objective in this study was to determine, by altering environmental and hydraulic conditions, whether fixed-film biological processes could be applied efficiently to completely recycled aquaculture wastewaters where ammonia and nitrite removal is critical for production of warm-water species of fish and invertebrates, including the freshwater prawn *Macrobrachium rosenbergii.*

LITERATURE REVIEW

Water quality management

Ammonia production by fish and invertebrates has been well studied though much of the physiology of excretion is complex and still largely uncertain. In freshwater prawns, and the order decapoda in general, a series of gills attached to each of the thoracic appendages functions both in respiration and excretion of wastes. Additionally, a large portion of ammonia is removed via fecal material. Antennal glands also function in excretion (McLaughlin, 1980).

Ammonia production rates and biochemical oxygen demand (BOD) production rates of prawns in larval, juvenile and adult stages were

TABLE 1

Water Quality Criteria for Aquaculture

Parameter	*US EPA (1976)*	*Roberts (1978)*	*Klontz et al. (1979)*	*Nightingale (1976)*	*Environment Canada (1979)*	*Suggested level*
Aluminum (mg liter^{-1})				0·2	0·1	<0·1
Ammonia (mg liter^{-1})	0·02	0·02	0·012	0·1	0·02	<0·02
Cadmium (mg liter^{-1})	1·2–12	0·4–3·0		0·05	0·2	Varied
Calcium (mg liter^{-1})			52			>52
Carbon dioxide (mg liter^{-1})			2·0			<2·0
Chromium (mg liter^{-1})	0·1	0·05		0·5	0·04	<0·1
Coliform (no. per 100 ml)	14					<14
Color units	75					<75
Copper (mg liter^{-1})	1·0	0·01	0·006	0·02	0·005	<0·01
Dissolved oxygen (mg liter^{-1})			5·0		4·0	>4·0
Iron (mg liter^{-1})	1·0		1·0	0·5	0·3	<0·5
Hardness (mg liter^{-1})				300		<300
Lead (mg liter^{-1})		0·03		0·1	0·03	<0·03
Magnesium (mg liter^{-1})						No data
Mercury (mg liter^{-1})		0·05			0·1	<0·1
Manganese (mg liter^{-1})	100					<100
Nitrate (mg liter^{-1})						No data
Nitrite (mg liter^{-1})		0·1	0·55			<0·1
pH	6·5–9	6·5–8·5	6·7–9	6·5–8	6·5–9	6·5–9
Sulfate (mg liter^{-1})						No data
Sulfide (mg liter^{-1})	0·002	0·002	0·002		0·002	<0·002
Specific conductance						No data
Temperature (°C)				50–90		Varies

(*continued*)

TABLE 1 – (*continued*)
Water Quality Criteria for Aquaculture

Parameter	*US EPA (1976)*	*Roberts (1978)*	*Klontz et al. (1979)*	*Nightingale (1976)*	*Environment Canada (1979)*	*Suggested level*
Total alkalinity (mg liter^{-1})	20		20-200		20	20-200
Total dissolved gas		110%	110%	105%		<105%
Total dissolved solids	250		400			<400
Total suspended solids		8	80		25	<25
Turbidity (mg liter^{-1})				60		<60
Zinc (mg liter^{-1})			0·04	0·1	0·03	<0·03

determined by several investigators (Nelson *et al.*, 1977; Armstrong *et al.*, 1978; Rogers and Klemetson, 1981). The major concern for application of design data in hatchery and aquaculture biofilter systems is the high water recirculation rates in hatchery and nursery tanks. A fixed media filter must be capable of handling dilute organic and ammonia loads but at high hydraulic loading. There is little written in the literature concerning treatment of such a waste. Management of the filter is an important consideration in obtaining nitrification and BOD removal from either fresh or saline aquaculture wastewater.

The toxicity of ammonia to aquatic life has been well documented. Wuhrman *et al.* (1947) provided evidence that the unionized fraction of ammonia was toxic to fish. They also showed the unionized portion was largely dependent on the pH of the water (European Inland Fisheries Commission, 1973). Mortality and morbidity to fish is the result of gill hyperplasia, resulting in inadequate transfer of gases and wastes between the capillaries and the aqueous environment (Roberts, 1978).

Although the EPA criterion of unionized ammonia for fishes and aquatic life is 0·02 mg liter^{-1} (US EPA, 1976), various species of fish exhibit varying degrees of susceptibility. The 144 h LC_{50} (concentration of unionized ammonia that is lethal to 50% of the organisms tested under given conditions for the specified time period) for *Macrobrachium rosenbergii* was determined by Armstrong *et al.* (1978), to be 0·80 mg liter^{-1} ammonia at a pH of 7·6. Ranges of toxic ammonia concentrations from 0·02 to 2·0 mg liter^{-1} unionized ammonia have been reported for freshwater aquatic life (US EPA, 1976). Additional work is necessary to verify and establish these toxic limits of unionized ammonia especially for the Malaysian prawn.

Nitrite has also been shown to be toxic to fishes and invertebrates. Smith and Williams (1974) found salmonids to be extremely sensitive to nitrite. In their study, gross examination of gill tissue and blood provided evidence that the fish suffered from methemoglobinemia involving the oxidation of hemoglobin to methemoglobin by nitrite. The fish die from anoxia, since methemoglobin is unable to transport oxygen. The criterion for nitrite was not considered in water quality criteria by the US EPA, since levels toxic to fishes are not usually found in natural waters. However, levels of nitrite accumulation should be considered in a reuse facility for production of fish and invertebrates. An LC_{50} value of 5 mg liter^{-1} nitrite during 168-h exposure was found for freshwater prawns (Kawaratani, 1978). The maximum level of nitrite tested with no deaths ranged from 9·7 mg liter^{-1} for 24 h to 1·8 mg liter^{-1} at 168 h.

Biofilters

Several investigators have described water recirculating systems using biofilters for intensive cultivation of salmon smolts (Burrows, 1964; Risa and Skjervold, 1975; Meade, no date), catfish (Broussard and Simco, 1976), trout (Speece, 1973; Mayo, 1976; Fyock, 1977; Harris, 1977), shrimp (Siddal, 1974; Mock *et al.*, 1975; McSweeny, 1977), tilapia (Otte and Rosenthal, 1979; Allison *et al.*, 1980), polyculture (Van Gorder, 1980), carp (Meske, 1976; Bohl, 1977), mariculture of clams and oysters (Forster, 1974), and the combination of fish culture with hydroponics in a single recirculation system (Lewis *et al.*, 1978). Few of the authors, however, discussed the basis for their choice of biofilter design parameters. There is little indication that the designs conform either to economic or resource minima for their declared purposes. Microbial population activity in the filter is essentially ubiquitous in distribution, spontaneously colonizing new filters, although inoculation can be expedited by addition of gravel from preexisting filters (Risa and Skjervold, 1975). The bacterial species that predominate at various depths of the filter are presumably self-selected, in response to environmental factors, such as the nutrient content, hydraulic flow and aeration of the filter bed, although their respective numbers are known to fluctuate until an equilibrium is established (Kawaii *et al.*, 1964). Rapid start-up of biofilters is possible by seeding with nitrifiers (Carmignani and Bennett, 1977).

Few approaches to analysis of design standards for biofilters in aquacultural applications are given in the literature. Hirayama reported on filter carrying capacity for a 300 liter marine aquarium containing one or two sea breams *Chrysophrys major* (Hirayama, 1966). Spotte (1970) cautioned that Hirayama's results need verification before accepting validity in freshwater, but there is reason to exercise a certain amount of skepticism in generalizing the results even for marine aquaria. One should keep in mind the small numbers of fish on which the results are based. Harris considered use of biological filters in hatchery water reuse systems. Submerged filters (Flexring and Flocor) were tested and found satisfactory in control of fish wastes. The basis for design of the biofilters used was presented by Speece (1973) for calculating substrate volume based on ammonia production rate divided by the nitrification rate (Harris, 1977).

The rotating biological contactor (RBC) has gained increased popularity over the past several years. This popularity is due to low power consumption and ease of operation. The transferability of design standards to aquacultural biofilters is limited, however, since aquaculture deals with a portion of the pollution spectrum far removed from domestic wastes. The effluent of treated sewage may contain as much as 5 mg liter^{-1} ammonia, some tenfold or more above the toxic limit for aquatic crops, such as shrimp (Cohen *et al.*, 1976).

The wastewater undergoes progressively increasing degrees of treatment as it flows from stage to stage in the contactor. Organic constituents of the wastewater are in high concentrations in the initial stages of the RBC. Cultures of filamentous and nonfilamentous bacteria develop that degrade the organic compounds. The concentration of organics decreases in the later stages, and higher life forms, including nitrifying bacteria appear, along with various types of rotifers and other predators (Antonie, 1976).

There are many reviews of biofilter use in the sanitary engineering profession. The annual literature review in the *Journal Water Pollution*

Control Federation presents current thinking related to biofilters in environmental problems. The review of literature for 1981 represents a doubling in the knowledge of RBC technology, the result of an RBC conference in Pennsylvania in 1980 (Smith *et al.*, 1980).

In another study, Antonie *et al.* (1974) stated that nitrification in an RBC begins when the BOD is below 30 mg liter^{-1}. Nitrifying organisms are able to compete at this concentration with the more rapidly growing heterotrophic organisms and establish themselves in the process. Nitrification is allowed to proceed rapidly, with the establishment of nitrifying organisms, until a BOD concentration of approximately 10 mg liter^{-1} is obtained and nitrification is complete.

Weng and Molof (1974) found that the chemical oxygen demand (COD) must be below 50 mg liter^{-1} for nitrification to occur. An artificial substrate with 50 mg liter^{-1} COD corresponded to a BOD concentration of approximately 14 mg liter^{-1}. This is less than half the concentration stated by Antonie *et al.* (1974) for nitrification.

METHODOLOGY

Design and construction of biofilters

Three biofilters were designed and constructed for use in this study. A fourth filter was obtained for use from the Clow Corp. in Beacon, New York. The units tested included a rotating biological contactor (Clow Corp.) with 16 discs of 25·4 cm (10 in) diameter, a 30·5 cm (12 in) diameter biodrum, an anaerobic downflow submerged filter 25·4 cm (10 in) diameter, and a trickling filter, also 25·4 cm (10 in) in diameter. All of the biofilters were laboratory-scale units. A schematic diagram of the biofilters system is presented in Fig. 1. Synthetic feedstock was pumped to a constant head tank so that flow rates to each filter could be controlled. The effluent from the four filters was discharged to the drain.

The submerged filter and trickling filter each had a capacity of 0·04 m^3 (1·4 ft^3). They were filled with 2·5–3·8 cm (1–1·5 in) slag with a specific surface area 18·3 m^2 m^{-3} (60 ft^2 ft^{-3}). The filters were fabricated from a section of 25·4 cm (10 in) PVC pipe with end discs cut from plexiglass. The outer shell of the biodrum was constructed from plastic netting provided by the Conwed Corp. Plexiglass discs of 30·5

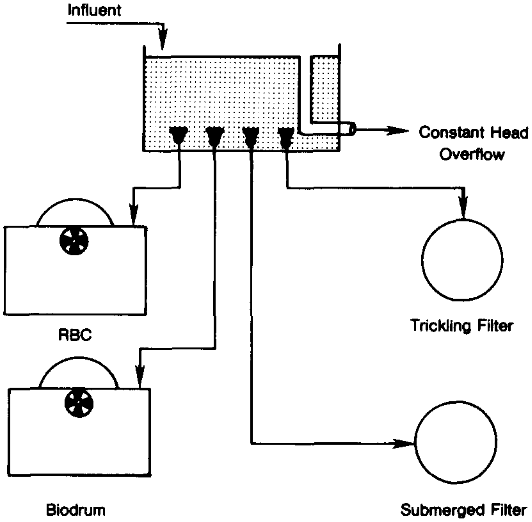

Fig. 1. Schematic diagram of laboratory scale biofilter setup.

cm (12 in) diameter provided support at the ends of the structure. The biodrum was filled with 2·5 cm (1 in) PVC rings that were cut in 2·5 cm (1 in) lengths from PVC pipe. The rotating biological contactor obtained from the Clow Corp. consisted of 16 plexiglass discs in four stages. The total surface area of the RBC was 1·58 m^2 (17 ft^2). The specifications of the four filters are given in Table 2.

TABLE 2
Specifications of Four Laboratory Scale Biofilters

Biofilter	*Volume container (m^3)*	*Support medium*	*Biofilm surface area (m^2)*
RBC	0·006	16–25·4 cm discs	1·66
Biodrum	0·057	2 000–2·5 cm rings	3·96
Submerged	0·039	2·5–3·8 cm slag	7·60
Trickling	0·039	2·5–3·8 cm slag	7·73

Note: 1 m^3 = 35·31 ft^3; 1 m^2 = 10·76 ft^2; 1 cm = 0·394 in.

Biofilter studies

The four biofilters were operated under a variety of conditions to determine efficiency of ammonia removal, optimum hydraulic loading and optimum conditions for application to aquaculture. While most parameters were not varied, flow rate, ammonia, salinity and temperature were altered to simulate conditions for prawn culture. The feedstock to the filters was freshwater, 5% seawater (prepared by diluting a commercial sea salts mix with freshwater), and 20% seawater, which corresponds to salt requirements of the adult, juvenile, and larval stages of growth, respectively. The influent used in the study was a synthetic feedstock solution (Table 3). At higher hydraulic loadings, a dilution system was designed to facilitate loading of this wastewater to the four filters and lessen the requirement for compounding the solution. The influent was developed based on data received from collaborators at the Hebrew University in Israel for wastewater produced in prawn growout facilities with reuse of the water and treatment by biological filtration. The synthetic feedstock was an approximation of actual water quality parameters measured in prawn production.

Sampling and analysis

Samples of influent and effluent to the four biofilters were taken daily at varied hydraulic loadings. Portions of the sample were fixed by

TABLE 3
Synthetic Feedstock Solution for Biofilter Study

	mg liter^{-1}
Dextrose	100
Yeast extract	10
Urea	5
Na_2HPO_4	40
$NaHCO_3$	125
$MnSO_4$	2
NH_4Cl	As needed

TABLE 4
Summary of Ranges of Biofilter Operational Conditions

	Influent	*Effluent*			
		Biodrum	*RBC*	*Trickling*	*Submerged*
Flow (m^3 m^{-2} day^{-1})		0·006-0·03	0·002-0·07	0·003-0·03	0·001-0·05
Ammonia (mg liter^{-1})	0·08-9·3	0·09-0·73	0·02-1·3	0·06-2·36	0·05-10·3
Alkalinity (mg liter^{-1})	146-246	181-226	181-250	143-250	144-246
BOD (mg liter^{-1})	29-84	1·7-6·5	2·3-5·2	15·8-25·7	27·1-71·0
COD (mg liter^{-1})	46-123	2·6-19·9	2·9-15·6	23·5-45·2	29·8-71·6
DO (mg liter^{-1})	0·1-6·5	1·9-5·4	3·3-6·6	0·32-6·6	0·1-5·0
Hardness (mg liter^{-1})	147-1010	161-974	161-1012	164-981	177-985
Nitrate (mg liter^{-1})	0-2·11	0·73-5·3	0·43-17·05	0·012-9·45	0·003-0·44
Nitrite (mg liter^{-1})	0·0004-0·6	0-0·219	0·007-0·29	0·002-0·168	0-0·03
pH	7·1-8·4	7·9-8·4	7·8-8·4	7·1-8·5	7·1-8·2
Temperature (°C)	25-30·8	24·5-27·0	22·5-25·0	25·5-30·0	25·0-30·0

Note: 1 m^3 m^{-2} day^{-1} = 24·545 gpd ft^{-2}.

adding 2 ml concentrated sulfuric acid per liter for COD analysis. All samples were stored at 4°C until analyzed. Temperature, dissolved oxygen, pH and ammonia were determined immediately after sampling while the other parameters were completed within one week. The fixed samples were used in the determination of COD. Other parameters analyzed in each of the biofilter samples include alkalinity (bicarbonate, carbonate and total), nitrate and nitrite. Additional tests performed on a less frequent basis included specific conductance, calcium, total hardness, chloride, sulfate and total non-filtrable residue. All of the tests were performed in an EPA certified laboratory to *Standard Methods for the Examination of Water and Wastewater* (APHA, 1976).

Calculation of unionized ammonia was made according to the procedures of Bower and Bidwell (1978) and Thurston *et al.* (1979).

RESULTS

Considerable data were generated in the analysis of several water quality parameters characterizing the operation of the four biofilters fed synthetic wastewater. The influent conditions of the biofilter study are summarized in Table 4. The hydraulic loading, ammonia concentrations, salinity and temperature were altered by varied influent conditions. The RBC provided the best treatment in terms of ammonia removal and BOD removal over the greatest range of hydraulic loads. Higher levels of hardness were due to runs at salinities of 5 and 20% seawater and not due to problems in sampling and analysis.

Table 5 presents average concentrations of ammonia, nitrite and nitrate throughout the study for various hydraulic loads. Again, it may be observed that the RBC performed best for ammonia removal. The data collected at higher salinities showed lower levels of ammonia, in part due to inherent problems in the analytical procedure (ammonia probe). The submerged filter performed well as an anaerobic denitrifying filter, as evidenced by very low levels of nitrate in the effluent.

Ammonia removal, nitrite production and nitrate production for various hydraulic loadings are presented in Table 6. Figure 2 shows the relationship of ammonia removal to hydraulic load for the three biofilters that removed ammonia. Note that the RBC removed over 90% of the ammonia at hydraulic loads up to 0·05 $m^3\ m^{-2}\ day^{-1}$ (1·2 gpd ft^{-2}). The biodrum efficiency of ammonia oxidation falls to below 90% at 0·024 $m^3\ m^{-2}\ day^{-1}$ (0·6 gpd ft^{-2}). Nitrification in the trickling filter is the least efficient, with ammonia removals less than 50% at hydraulic loads above 0·012 $m^3\ m^{-2}\ day^{-1}$ (0·3 gpd ft^{-2}). From a removal standpoint, the RBC seems to be the best process since high removals are observed at a wide range of hydraulic loads.

Figure 3 presents the levels of un-ionized ammonia concentration for the four biofilters at varied hydraulic loadings. The data have been standardized for warmwater aquaculture. It was assumed that, in all cases, the water temperature and pH were 30°C and 8, respectively. The results show that the RBC would provide adequate water quality

TABLE 5

Average Ammonia, Nitrite and Nitrate Levels at Varied Hydraulic Loadings

Date (month/	Influent			Biodrum				RBC				Trickling				Submerged			
day)	NH_3	NO_2	NO_3	NH_3	NO_2	NO_3	Flow	NH_3	NO_2	NO_3	Flow	NH_3	NO_2	NO_3	Flow	NH_3	NO_2	NO_3	Flow
5/17	3·5	0·003	0·02	0·35	0·05	0·73	0·020	0·02	0·007	0·43	0·021	1·35	0·007	0·05	0·017	7·5	0·002	0·01	0·016
5/31	4·0	0·003	0·03	0·20	0·025	3·2	0·017	0·07	0·04	0·97	0·019	1·66	0·002	0·04	0·024	5·0	0·004	0·06	0·025
6/7	3·5	0·0004	0·02	0·62	0·04	2·19	0·033	0·10	0·18	1·19	0·032	2·15	0·004	0·012	0·032	3·6	0·001	0·003	0·032
6/29	4·0	0·008	0·16	0·73	0·20	4·17	0·017	0·64	0·29	1·5	0·041	2·36	0·003	0·01	0·016	4·4	0·007	0·034	0·049
7/6	3·6	0·006	0·28	0·28	0·11	2·33	0·017	0·16	0·03	1·18	0·049	1·83	0·04	0·17	0·009	4·6	0·002	0·044	0·017
7/12	3·6	0·01	0·19	0·56	0·18	1·88	0·026	0·25	0·02	1·27	0·063	1·6	0·08	0·26	0·009	5·0	0·003	0·07	0·024
7/19	3·8	0·006	0·19	0·14	0·06	1·21	0·016	1·3	0·06	0·99	0·073	–	–	–	–	5·3	0·011	0·04	0·033
7/26	3·2	0·006	0·23	0·25	0·04	1·54	0·016	0·26	0·02	0·75	0·040	1·75	0·16	0·32	0·008	3·7	0	0·07	0·025
8/2	1·8	0·04	0·25	0·15	0·02	0·79	0·017	0·13	0·02	0·51	0·040	0·70	0·16	0·73	0·008	3·2	0·003	0·02	0·025

Ammonia, nitrate and nitrite values are weekly averages in mg liter^{-1}.
Flow rate is in m^3 m^{-2} day^{-1} to the given filter.
Data on week of 7/26 with 5% seawater.
Data on week of 8/2 with 20% seawater.
Note: 1 m^3 m^{-2} day^{-1} = 24·545 gpd ft^{-2}.

TABLE 6

Percent Ammonia Removal and Nitrite and Nitrate Production at Various Hydraulic Loadings

Date (month/ (day)	Biodrum				RBC				Trickling				Submerged			
	NH_3	NO_2	NO_3	Flow	NH_3	NO_2	NO_3	Flow	NH_3	NO_2	NO_3	Flow	NH_3	NO_2	NO_3	Flow
5/17	90	94	97	0·020	99	57	95	0·021	38	57	63	0·017	−53	−33	−30	0·016
5/31	95	88	99	0·017	98	93	97	0·019	42	−33	25	0·024	−20	25	53	0·025
6/7	82	99	99	0·033	97	99	98	0·032	39	−90	−40	0·032	−3	−75	−85	0·032
6/29	82	96	96	0·017	84	97	89	0·041	41	63	92	0·016	−8	−13	−79	0·049
7/6	92	93	93	0·017	96	78	76	0·049	49	−83	39	0·009	−22	−67	−77	0·017
7/12	84	97	90	0·026	93	50	85	0·063	56	−87	−27	0·009	−28	−70	−63	0·024
7/19	96	82	84	0·016	69	90	81	0·073	-	−	−	−	−28	−83	−79	0·033
7/26	92	85	85	0·016	92	67	89	0·040	45	96	28	0·008	−14	−100	−68	0·025
8/2	90	75	71	0·017	93	74	51	0·040	61	76	66	0·008	−44	−93	−92	0·025

Percent ammonia removal.
Percent nitrate production.
Percent nitrite production.
Flow rate is in $m^3\ m^{-2}\ day^{-1}$.
Note: $1\ m^3\ m^{-2}\ day^{-1} = 24{\cdot}545$ gpd ft^{-2}.

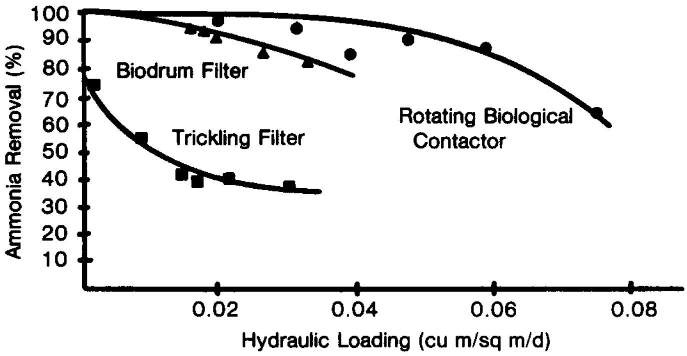

Fig. 2. Relationship between ammonia removal and hydraulic loading.

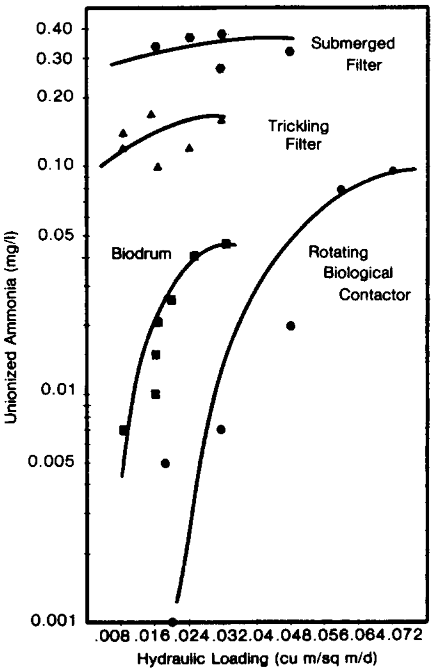

Fig. 3. Comparison of four fixed-film processes for maintenance of unionized ammonia levels required for fish culture.

for warmwater aquaculture (less than 0·02 mg unionized ammonia liter^{-1}) at hydraulic loading rates up to 0·04 m^3 m^{-2} day^{-1} (1·2 gpd ft^{-2}). The biodrum could be utilized up to a hydraulic load of 0·016 m^3 m^{-2} day^{-1} (0·4 gpd ft^{-2}). The other processes did not maintain unionized ammonia levels below the 0·02 mg liter^{-1} required for warmwater aquaculture.

DISCUSSION

The major consideration of aquaculturists is the economic production of animals. Aquaculturists are, therefore, very concerned about how water quality may affect the rate of return on investment. Few private ventures have included biological processes in their treatment schemes for rearing fish and/or invertebrates. The concerns at present are the high capital costs of water treatment systems, the need for back-up chemical or physical treatment systems, cost of water quality monitoring and the uncertainty of morbidity and mortality to the fish population due to the continual reuse of the water supply. These concerns have caused most fish culturists to develop sites in areas where water is abundant and a flow-through system is warranted.

The data gathered in this study will aid the engineer and aquaculturist in design and maintenance of biological filtration systems applied in reuse facilities for production of fish and invertebrates. The removal of ammonia and subsequent production of nitrite and nitrate have been presented for different conditions. The results of this study may be used to size fixed film processes for warmwater aquaculture. Speece (1973) and Fyock (1977) suggested that filters be sized based on the ammonia production rates (APR) of the cultured species. In the case of trout culture, the APR was 0·018 kg ammonia 100 kg trout day^{-1}. In similar work done by the author and reported earlier (Rogers and Klemetson, 1981), for freshwater prawns, ammonia production was 0·021 kg ammonia/kg prawns day^{-1}. The specific surface area required in Fyock's calculations was determined by the following equation:

$$\text{Specific surface area} = \frac{\text{Ammonia production rate}}{\text{Nitrification rate}}$$

where the nitrification rate or ammonia removal rate was 0·56 g total ammonia $\text{m}^{-2}\ \text{day}^{-1}$ (0·00015 lb ammonia $\text{ft}^{-2}\ \text{day}^{-1}$). The data obtained in the present study from ammonia removal yielded a nitrification rate of 2·83 g $\text{m}^{-2}\ \text{day}^{-1}$ (0·00058 lb $\text{ft}^{-2}\ \text{day}^{-1}$) for the RBC. This higher value would be expected since Speece's work is for trout reared at 4.4–16°C (40–60°F) and the present study is for prawn culture at 31°C (87°F).

Water quality management

Biofilters can provide adequate removal of ammonia and organics from aquaculture wastewaters. The RBC and biodrum were shown capable of providing acceptable water quality for warmwater aquaculture in a reuse system. Those processes should be included in hatchery and growout systems that either require or are suited to complete reuse of the available water supply. On the other hand, the trickling filter and submerged filter were not capable of providing needed water quality under tested conditions. This observation correlates with the work of aquaculture engineers and hatchery supervisors who have found that some biological filtration processes are unreliable (David Owsley, personal communication, Dworshak National Fish Hatchery, Idaho). The biofilters they used were downflow trickling or submerged filters with support media including oyster shell, stone, or slag.

An important consideration for aquaculture reuse systems is management and operation of the biological filter. Very little work has been done in this area. The results of this study indicated that artificial control of waste stream chemical characteristics could enhance the nitrification process. Supplemental addition of ammonium salts to maintain a constant level of unionized ammonia in the filter influent could improve the process. Ammonia removals in the RBC, biodrum and trickling filter were highest when steady state ammonia levels were maintained.

Another consideration is the dissolved oxygen level through the biological filter and in the fish rearing tanks or raceways. Biological ammonia removal was shown to be reduced greatly if the concentrations of oxygen are allowed to drop below 2 mg liter^{-1} as evidenced in the submerged filter and to a limited extent in the trickling filter. Supplemental aeration of the biofilter through addition of diffused air may be required to optimize the oxidation of ammonia.

SUMMARY AND CONCLUSIONS

Fixed-film biological filters are capable of providing adequate removal of nitrogen compounds from aquaculture wastewaters. They should be considered for facilities where there is partial or complete reuse of the water supply. The present study has examined four biofiltration processes from the standpoint of ammonia removal and the process of nitrification as it relates to the concentration of ammonium and nitrite in treated water. The major findings and conclusions of the project are given below:

1. Three fixed-film biological filters (rotating biological contactor, biodrum and trickling filter) were capable of removing ammonia and nitrite.
2. The rotating biological contactor provided the highest ammonia removals (above 90%) over a wide range of hydraulic loads to 0·05 $m^3 m^{-2} day^{-1}$ (1·2 gpd ft^{-2}).
3. The trickling filter was, in comparison to the RBC, much less efficient. Only 50% of the ammonia was removed at a loading of 0·012 $m^3 m^{-2} day^{-1}$ (0·30 gpd $ft^{-2} day^{-1}$). A very large filter would be required to provide the same treatment that may be achieved by a small RBC.
4. The biodrum provided ammonia removal efficiencies of over 80% up to a hydraulic load of about 0·04 $m^3 m^{-2} day^{-1}$ (0·9 gpd ft^{-2}).
5. The submerged anaerobic filter was effective in removing nitrate (denitrification). The process could be coupled with any of the aerobic filters for complete removal of the inorganic nitrogen in the waste stream.

ACKNOWLEDGEMENTS

This work was funded by the Binational Agricultural Research and Development Agency (BARD) which sponsors projects between the United States and Israel. Special thanks are given for the needed support in materials, supplies and stipend through project number US-60-80.

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