Fish Aqua Sci 13(2), 133-139, 2010

KOSFAS FISHERIES AND AQUATIC SCIENCES
The Korean Society of
Fisheries and Aquatic Science

Serial Particle Size Fractionation and Water Quality in a Recirculating Aquaculture System for Eel

Jinhwan Lee*
Research Institute of Marine Science and Technology,
Korea Maritime University, Busan 606-791, Korea

The effects of suspended solids size on culture water quality were determined in a commercial recirculating aquaculture system (RAS) for Japanese eel, *Anguilla japonica*. The particulate phase of the culture water was serially divided into six size fractions using 300, 200, 100, 75, 45, and 26 μm pore size stainless sieves. The total, dissolved, and particulate nitrogen and phosphorus, and suspended solids for each fraction were determined. The concentration ranges in the fractions were: total nitrogen, 164-148 mg L^{-1}; total phosphorus, 20.4-15.5 mg L^{-1}; and total suspended solids, 8.1-6.1 mg L^{-1}. The concentration of total nitrogen and total phosphorus decreased significantly ($P<0.05$) with a 26 μm and 200 μm filter pore size, respectively. Nutrients from dissolved organic substances were much higher than from particulates. Analysis of particle size fractionation and its effects on water quality is useful to estimate removal efficiencies of a commercial effluent screening device for solid management and development of solid removal systems.

Key words: Recirculating aquaculture system (RAS), Suspended solid, Solid removal, Total nitrogen, Total phosphorus, *Anguilla japonica*.

Introduction

Suspended solids management is a key factor determining the success of a recirculating aquaculture system (RAS) because of its potential impact. Organic particulates are very harmful to fish health (Chapman et al., 1987) and must be removed for successful water management (Spotte, 1979). A build-up of solids in an RAS leads to a decline in culture water quality, which increases stress on culture organisms (Rosenthal et al., 1982; Klontz et al., 1985; Braaten et al., 1986). Recycling suspended particles in an RAS adversely affects fish through partial smothering of gills (Muir, 1982), aids in the propagation and proliferation of pathogenic organisms (Braaten et al., 1986; Liltved and Cripps, 1999), and consumes dissolved oxygen as the solids decay (Welch and Lindell, 1992). Recycling suspended particles also potentially clogs biofilters and reduces their nitrification efficiency. In addition, suspended solids mineralize to produce ammonia (Liao and Mayo, 1974).

Since the adverse effects of solids on RASs were recognized, studies on solids characteristics (Chen et al., 1993; Twarowska et al., 1997; Maillard et al., 2005) and solids removal (Liao, 1980; Wickins, 1980; Cripps and Bergheim, 2000; Lekang et al., 2000; Summerfelt and Penne, 2005) have increased.

Solid waste accumulation may become the first limiting parameter of an RAS as recycle rate increases. Although various solid removal systems have been used to remove solid waste, small particles, which are not trapped by the filter, accumulate. However, basic information on the size distribution of solids and their effect on water quality are still lacking. In particular, information on particle size fractionation and nutrient analysis would be useful for characterizing eel culture waste and improving recycling water treatment efficiency.

Japanese eel, *Anguilla japonica*, is one of the most important freshwater aquaculture species in Korea, China, and Japan, and other species, such as *Anguilla anguilla*, are also important culture species in southern Asia and Europe. For successful and energy effective culture of eel, there is a need to develop highly efficient solid removal systems in RASs.

---

*Corresponding author: jinhwanlee@hhu.ac.kr

The objective of this study was to investigate the particulate fractions in the water of an eel RAS on water quality parameters such as total nitrogen (TN), total dissolved nitrogen (TDN), total phosphorous (TP), total dissolved phosphorous (TDP), total organic carbon (TOC), dissolved organic carbon (DOC), total suspended solid (TSS), and total volatile solid (TVS) for solids control process design.

Materials and Methods

RAS and experimental conditions

The experiment was conducted in an RAS for Japanese eel (Fig. 1) at Kywangkye-ri, Changyeong-gun, Gyeongsangnam-do. The RAS consisted of ten circular culture tanks (6 m diameter and 29 m^3 water volume), a microscreen drum filter (1.5 m diameter and 8.47 m^2 surface area), a sedimentation chamber (96.6 m^3 water volume), a static biofilter chamber (96.6 m^3 water volume) equipped with static scrub-pad filter media, three biofilter chambers (290 m^3 water volume) containing plastic beads, and a heating chamber (96.6 m^3 water volume). Each circular fish-rearing tank had a sidewall drain which removed water from the bottom-center through two PVC pipes (50 mm diameter). The effluent from the culture tanks discharged into a drum filter (60 µm mesh), which functioned mainly for solids removal. Drum-filtered water flushed into a sedimentation chamber and then into the biofilter tanks. Filtered water was pumped into the culture tanks and recycled (Fig. 1). A 10 hp electric centrifugal pump lifted the filtered water into the culture tanks. A 1.5 hp electric centrifugal pump was mounted beside each culture tank to circulate the culture tank water and increase the dissolved oxygen (DO). Aeration was provided to the water both in the culture tanks and the biofilters containing plastic beads.

During the sampling time, the RAS contained approximately 66,000 eel, and the total biomass was 9,900 kg (35.3 kg/m^2). The amount of feed inputted daily was approximately 280 kg (2.8%) of the total biomass (Purina EEGJ30011 paste feed: crude protein, 51.7%; crude lipid, 5.8%; phosphorus, <1.8%; crude fiber, <3%; crude ash, 13.1%). The daily freshwater inflow was 1% of the total system volume, which was lost due to drum filter backwashing. Heating boilers and thermostats kept the water temperature constant at 28°C.

Sample collection and particle size fractionation

To exclude changes in the experimental conditions, the fish were fasted 1 day before water sampling. Water samples were collected from the inlet of the microscreen drum filter. To minimize variability in the particulate parameters, each size-fractioned 1 L sample was collected from 20 L of a size-fractioned sample vessel. The effluent samples were serially filtered using Korean standard micro sieves (200 mm diameter, 100 µm thickness, Chung Gye Ins. Co., Seoul, Korea) with pore sizes of 300, 200, 100, 75, 45, and 26 µm. The filtration and particle-size fractioned samples were measured during on-site sampling, so that the possibility of physical and chemical changes prior to analysis was reduced.

Water quality

For solids fractionation and its effects on water quality, both unfiltered and filtered effluent samples were analyzed according to standard methods (APHA, 1998). The TOC and DOC were determined by the wet oxidation method. Alkaline potassium persulfate

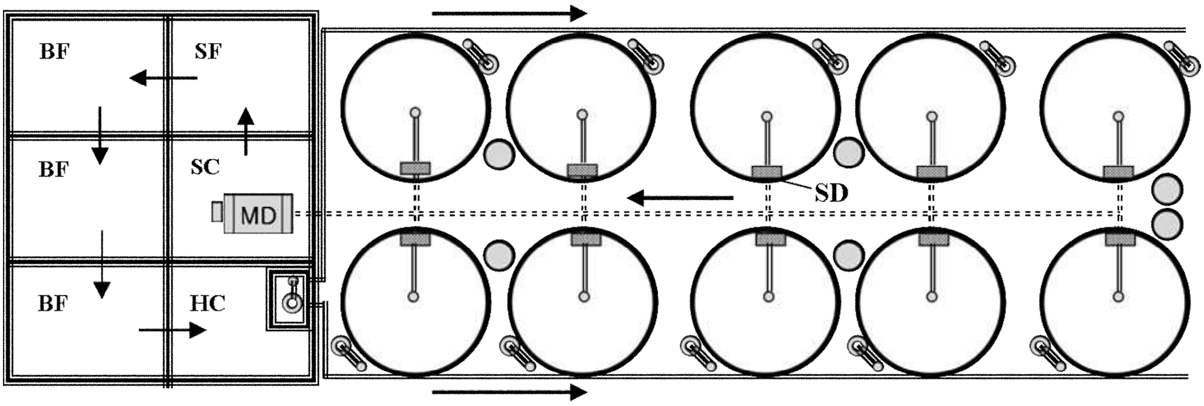

Fig. 1. Schematic drawing of commercial eel recirculating aquaculture system: SD, sidewall drain; MD, microscreen drum filter; SC, settling chamber; SF, static filtration chamber; BF, bead filtration chamber; HC, heating chamber.

oxidation was used to determine the TN, TDN, TP, and TDP (Grasshoff et al., 1983). All water quality parameters were determined in triplicate. The DO and pH were measured using a meter (HACH, HQ30d; Loveland CO, USA).

Statistical analysis

A one-way analysis of variance and Duncan's multiple range test were used to analyze the differences in water quality among unfiltered and size fraction sample groups using the SAS software package, Version 9.1 (SAS Institute Inc., Cary, NC, USA). $P<0.05$ was considered statistically significant.

Results

The mean water quality and particle parameters in the unfractionated culture tank effluent are shown in Table 1. The TDN was approximately 87% of the TN, and the TDP was approximately 85% of the TP. The mean TSS was 8.1 mg L^{-1}. The DO and pH were maintained at 7.8 mg L^{-1} and 6.8, respectively, by adding pure liquid oxygen and calcium carbonate, respectively.

Serial particle fractionation of the culture tank effluent decreased the TN nutrient concentration; however, a significant ($P<0.05$) concentration change was obtained only from the 26-µm pore filtration size (Fig. 2). The mean TN concentration decreased from 164.1 to 158.6 mg L^{-1}, a 3.3% reduction, with a 200 µm pore size filtration. TN reduction rate increased to 9.8% after decreasing the mesh size to 26 µm. TDN was not significantly ($P>0.05$) different according to the serial particle-size fractionation. TPN decreased significantly with the use of a 26 µm pore size filter (Fig. 2).

The mean TP concentration decreased from 20.4 to 15.5 mg L^{-1}, a 24.0% reduction, with decreasing mesh size (Fig. 3). A significant ($P<0.05$) reduction in TP was achieved using a 200 µm pore size filter. The mean TDP and total particulate phosphorus (TPP) concentrations also decreased from 17.3 to 15.0 mg L^{-1}, and 3.0 to 0.5 mg L^{-1}, respectively (Fig. 3). Significant ($P<0.05$) TDP and TPP reductions were achieved with the use of 100- and 200 µm pore size filters, respectively.

The mean TOC, DOC, and particulate organic carbon (POC) concentrations in filtered culture tank effluent ranged from 13.2 to 10.9 mg L^{-1}, 12.1 to 9.4 mg L^{-1}, and 1.5 to 1.0 mg L^{-1}, respectively (Fig. 4). The mean DOC fluctuated according to the serial fractionation of the effluent. A significant DOC increment was observed with the use of 100- and 75 µm pore size filters. An increased POC concentration was observed for the later filtration samples using filters finer than 75 µm. However, a significant POC increment compared with unfiltered effluent was found at a pore size of 26 µm (Fig. 4).

The mean TSS concentration decreased from 8.1 to 6.1 mg L^{-1}, a 24.6% reduction, with decreasing mesh size (Fig. 5). The mean total volatile solid (TVS) concentration also decreased from 7.6 to 5.3 mg L^{-1}, a 30.2% reduction, with decreasing mesh size (Fig. 5).

Discussion

The effective and economical waste management is necessary in an RAS, as waste material in aquaculture effluents occurs in low concentrations and at high water flow rates (Cripps, 1994; Gowen et al., 1991; Pillay, 1992). Basic solids information, such as specific gravity, settling velocity, and size distribution, has been provided (Chet at al., 1993), but research on both nutrient and particle size fractionation is lacking.

As noted by Cripps (1995), parametric multiple filtration may adversely influence the character of the effluent, so we obtained samples for each particle size fraction from a sample pool (20 L). The nutrient concentration from serial fractionation decreased with decreasing mesh size, which was similar to previous studies (Chen et al., 1993; Cripps, 1995) and can be explained from the particle volume and nutrient distributions according to size fractionation. Unlike this study, Cripps (1995) found a significantly greater concentration of TPP in suspended solids containing

Table 1. Mean water quality parameters in the unfractionated culture tank effluent from a recirculating aquaculture system for eel

Parameter	Total		Total dissolved		Total particulate	
	Mean	s.e.	Meam	s.e.	Mean	s.e.
TN (mg L^{-1})	164.1	2.86	142.8	2.47	21.3	4.67
TP (mg L^{-1})	20.4	0.50	17.3	0.21	3.1	0.67
TSS (mg L^{-1})	8.1	0.2	-		-	
DO (mg L^{-1})	7.8	1.87	-		-	
pH	6.8	0.4	-		-	

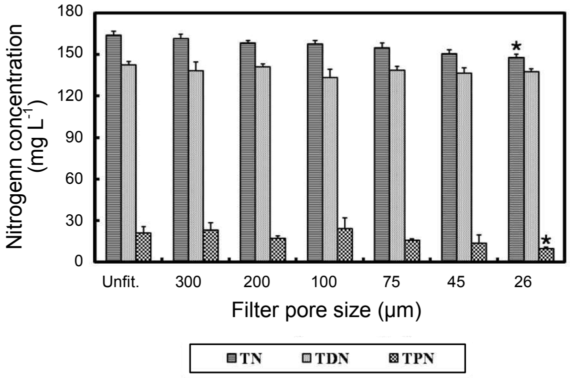

Fig. 2. Nitrogen concentration changes of culture water with increasing filtration effort: Unfilt., unfiltered effluent; TN, total nitrogen; TDN, total dissolved nitrogen; TPN, total particulate nitrogen. Values (mean ± s.e.) with aster (*) indicate statitically significant differences ($P<0.05$) with concentration of unfiltered effluent.

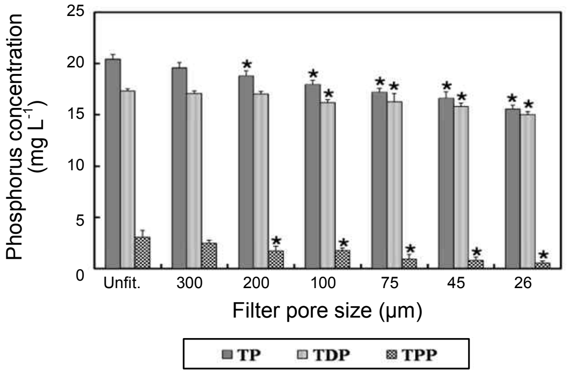

Fig. 3. Phosphorus concentration changes of culture water with increasing filtration effort: Unfilt., unfiltered effluent; TP, total phosphorus; TDP, total dissolved phosphorus; TPP, total particulate phophorus. Values (mean ± s.e.) with aster (*) indicate statistically significant differences ($P<0.05$) with concentration of unfiltered effluent.

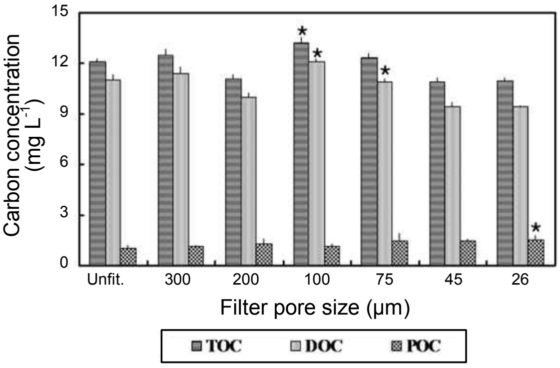

Fig. 4. Carbon concentration changes of culture water with increasing filtration effort: Unfilt., unfiltered effluent; TOC, total organic carbon; DOC, dissolved organic carbon; POC, particulate organic carbon. Values (mean ± s.e.) with aster (*) indicate statistically significant differences ($P<0.05$) with concentration of unfiltered effluent.

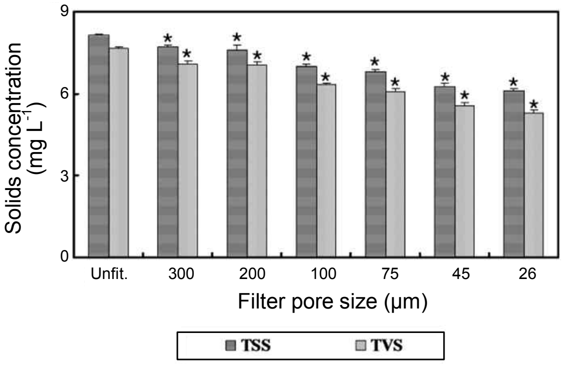

Fig. 5. Solids concentration changes of culture water with increasing filtration effort: Unfilt., unfiltered effluent; TSS, total suspended solids; TVS, total volatile solids. Values (mean ± s.e.) with aster (*) indicate statistically significant differences ($P<0.05$) with concentration of unfiltered effluent.

smaller particles (11.3-13.4 μm) than in larger particles. No clear trends in TPN concentrations according to size fractions both in this and Cripps (1995)'s study are analogous to the pattern of nutrient and size fractionation in aquaculture effluent.

In the present study, small particles, which could not be removed by the filter and recycled or accumulated, were considered. Thus, fish were fasted for 24 hours before water sampling to eliminate variability caused by factors such as diurnal feeding cycles, culture system management irregularities, or tank cleaning operations.

In the current study, solid particles were mainly removed by a microscreen drum filter with a mesh size of 60 μm. Cripps (1995) reported that the TSS concentration of smaller particles was considerably less than that of larger particles. From the results of this study, a reduction in TSS by microsieve filtration seemed to be effective using a 75 μm mesh size. A further reduction in filter pore size would be expected to produce negligible results on the TSS removal efficiency and, in practice, would be difficult to operate.

The shapes of the unfiltered and size-fractioned particles under a light microscope were irregular; thus, elongated particles may have passed through pore sizes smaller than the mean diameter. This result indicates that solid removal for the finest target size

Table 2. Comparison of treatment efficiencies for total nitrogen (TN), total phosphorus (TP) and solids, using different pore size screens from previous studies and this study

Screen	Pore size (µm)	Effluent quality parameter reduction (%)			Reference
		TN	TP	Solids	
Unik microscreen	350, 60	7-30	40	40	Bergheim et al. (1991)
Bowed screen	250	42.7	49.3	74.4	Lekang et al. (2000)
Micro sieve	300, 200, 100	1.4-3.7	4.4-12.3	5-13.5	This study
Membrane	100	14	30	30	Cripps (1995)
Micro sieve	75	5.7	15.7	16	This study
Membrane	65	23	36	42	Cripps (1995)
Microscreen	60	37	57	70	Eikebrokk et al. (1995)
Micro sieve	45, 26	8.2-9.9	18.6-24	23.4-24.6	This study

in an RAS would be unavailable using only microscreen filtration process.

Typical mechanical screen filters are usually designed to remove particles greater than 80 µm, leaving smaller particles to accumulate. A majority of these fine suspended particles remain even after water passes repeatedly through biological filters (Muir, 1978). As a result, suspended particle concentrations in RASs often exceed the recommended limit of 15 mg L^{-1} (Reinemann, 1987; Timmons et al., 1987).

There is a significant amount of water quality analysis data for aquaculture effluents (Foy and Rosell, 1991b; Eikebrokk et al., 1995; Qian et al., 2001); however, little work has been conducted to quantify nutrients according to particle size with the aim of using the results to improve treatment efficiency (Bergheim and Forsberg, 1993; Bergheim et al., 1993a).

In the present study, nutrients from dissolved organic substances were predominant over those from particulates. According to Hirayama et al. (1988), dissolved organic substances in a closed-recirculation aquarium increase with the cumulative amount of feed. From their results, the carbon, nitrogen, and phosphorous in the organic substances accumulating in the culture water accounted for 3.2% of the feed supplied. In the commercial-scale culture system used in this study, no significant trends occurred for the TOC and DOC concentrations according to the size fraction. However, finer particles contained much higher particulate organic carbon. This suggests that the finer particles are the core material of various sizes of suspended solids and may originate from the bone material in the fishmeal.

Table 2 summarize the results of the TP, TN, and solid filtration efficiencies from other studies and the current study. The reduction trends achieved in this study were lower than those achieved by other studies. The efficiencies achieved by Bergheim et al. (1991) and Eikebrokk et al. (1995) were attained using devices that treated the effluent in situ. The nutrient and solid concentrations in other studies were also lower than this study. Moreover, in this study, dissolved nutrients were predominant over particulates, and serial filtration of size fractions only reduced the particle volume. These might be the reasons for the lower reduction efficiencies using mechanical filtration. According to Foy and Rosell (1991a) and Bergheim et al. (1993b), 7-32% of the TN and 30-84% of the TP was in the particulate fraction. In the present study, a similar ratio of 7-16% of the TN, but a considerably lower ratio of 3-15% of the TP was found in the particulate fraction. The lower concentration of TPP might be explained by differences in feed, fish biomass, and culture species.

Most studies that have focused on solid characteristics have been conducted with salmonids and tilapia; however, there is a lack of data for eels supplied a paste feed. This makes a direct comparison of the solid characteristics results from an RAS difficult.

Solid characteristics, e.g., particle size distribution and nutrients in the particle size fractions, are necessary data to design and improve solid removal systems. Analyses of solid characteristics are expected to increase for evaluating filtration systems for other fish species.

Acknowledgement

This work was supported by a National Research Foundation of Korea grant funded by the Korean Government [KRF-2009-353-F00027].

References

APHA (American Public Health Association). American Water Works Association, and Water Environment Federation. 1998. Standard Methods for the Examination of Wastewater, 20th ed. Washington, DC.

Bergheim A and Forsberg OI. 1993. Attempts to reduce effluent loadings from salmon farms by varying feeding frequencies and mechanical effluent treatment. Production, Environment and Quality. Bordeaux Aquaculture '92. In: Barnabe G and Kestemont P, eds. European Aquaculture Society Special Publication No. 18, Ghent, Belgium, 115-124.

Bergheim A, Aabel JP and Seymour EA. 1991. Past and present approaches to aquaculture waste management in Norway net pen operations. Nutritional Strategies and Aquaculture Waste. Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste. In: Cowey CB and Cho CY, eds. University of Guelph, Guelph, Canada, 117-136.

Bergheim A, Kristiansen R and Kelly LA. 1993a. Treatment and utilization of sludge from landbased farms for salmon. In: Techniques for Modern Aquaculture. Wang J-W, ed . Proceedings of an Aqua-culture Engineering Conference, 21-23 June 1993, Spokane, WA. American Society of Agriculture Engineers, St. Joseph, MI, 486-495.

Bergheim A, Sanni S, Indrevik G and Hølland P. 1993b. Sludge removal from salmonid tank effluent using rotating microsieves. Aquacult Eng 12, 97-109.

Braaten B, Poppe T, Jacobsen P and Maroni K. 1986. Risks from self-pollution in aquaculture: evaluation and consequences. In: Grimaldi E and Rosenthal H, eds. Efficiency in aquaculture production: Disease and control. Proceedings of the 3rd international conference on aquafarming 'Aquacoltura'86'. Verona, Italy, Oct. 9-10, 1986, 139-165.

Chapman PE, Popham JD, Griffin J and Michaelson J. 1987. Differentiation of physical from chemical toxicity in solid waste fish bioassay. Water Air Soil Pollut 33, 295-308.

Chen S, Timmons MB, Aneshansley DJ and Bisogni JJ Jr. 1993. Suspended solids characteristics from recirculating aquacultral systems and design implications. Aquaculture 112, 143-155.

Cripps SJ. 1995. Serial particle size fractionation and characterization of an aquacultural effluent. Aquaculture 133, 323-339.

Cripps SJ. 1994. Minimizing outputs: treatment. J Appl Icthyol 10, 284-294.

Cripps SJ and Hanaeus J. 1994. The effects of chemical precipitation by slaked lime on suspended particle dynamics in wastewater ponds. Water Sci Technol 28, 215-222.

Cripps SJ and Bergheim A. 2000. Solids management and removal for intensive land-based aquaculture production systems. Aquacult Eng 22, 33-56.

Eikebrokk B, Piedrahita R and Ulgenes Y. 1995. Rates of fish waste production and effluent discharge from a recirculating system (BIOFISH) under commercial conditions. Aquaculture Research 589-599.

Foy RH and Rosell R. 1991a. Fractionation of phosphorus and nitrogen loadings from a Northern Ireland fish farm. Aquaculture 96, 31-42.

Foy RH and Rosell R. 1991b. Loadings of nitrogen and phosphorus from a Northern Ireland fish farm. Aquaculture 96, 17-30.

Gowen RJ, Weston DP and Ervik A. 1991. Aquaculture and the benthic environment: a review. Nutritional Strategies and Aquaculture Waste. Proceedings of the First International Symposium on Nutritional Strategies in Management of Aquaculture Waste. In: Cowey CB and Cho CY, eds. University of Guelph, Guelph, Ont., Canada, 1990, 187-205.

Grasshoff K, Ehrhardt M, Kremling K. 1983. Method of Seawater Analysis, Verlag. Chemie. 205p.

Klontz W, Stewart BC and Eib DW. 1985. On the etiology and pathophysiology of environmental gill disease in juvenile salmonids. In: Ellis AE, ed. Fish and shellfish pathology, Academic Press, London, 199-210.

Lekang OI, Bergheim A and Dalen H. 2000. An integrated wastewater treatment system for land-based fish-farming. Aquacultural Engineering 22, 199-211.

Liao PB. 1980. Treatment units used in recirculation systems for intensive aquaculture. Symposium on New Developments in the Utilization of Heated Effluents and Recirculation Systems for Intensive Aquaculture, EIFAC, 11th Session, Stabanger, Norway, 28-30 May, 1980.

Liao PB and Mayo RD. 1974. Intensified fish culture combining water reconditioning with pollution abatement. Aquaculture 3, 61-85.

Liltved H and Cripps SJ. 1999. Removal of particle associated bacteria by prefiltration and ultraviolet irradiation. Aquacult Res 30, 445-450.

Maillard VM, Boardman GD, Nyland JE and Kuhn DD. 2005. Water quality and sludge characterization at raceway-system trout farms. Aquacult Eng 33, 271-284.

Muir JF. 1982. Recirculated system in aquaculture. In: Muir JF and Roberts RJ, eds. Recent Advances in Aquaculture, Vol. 1. Croom Helm and Westview Press, London, 358-446.

Pillay TVR. 1992. Aquaculture and the Environment. Fishing News Books, Oxford, 56-77.

Qian P-Y, Wu MCS and Ni I-H. 2001. Comparison of nutrients release among some maricultured animals. Aquaculture 200, 305-316.

Reinemann DJ. 1987. A Theoretical and Experimental Study of Air Lift Pumping and Aeration with Reference to Aquaculture Applications. PhD dissertation, Cornell University, Ithaca, NY, 100.

Rosenthal H, Hoffmann R, Jorgensen L, Kruner G, Peters G, Schlotfeldt HJ and Schomann H. 1982. Water management in circular tanks of a commercial intensive culture unit and its effects on water quality and fish condition. ICES Statutory meeting, C.M. 1982/F:22, 13.

Spotte SH. 1979. Seawater Aquariums, the Captive Environment. Wiley, New York, 413.

Stickney RR. 1979. Principles of Warm Water Aquaculture. Wiley Interscience, New York, 375.

Summerfelt RC and Penne CR. 2005. Solids removal in a recirculating aquaculture system where the majority of flow bypasses the microscreen filter. Aquacultural Engineering 33, 214-224.

Timmons MB, Youngs WD, Regenstein JM, German GA, Bowser PR and Bisogni CA. 1987. A Systems Approach to the Development of an Integrated Trout Industry for New York State. Final Report Presented to the New York State Department of Agriculture and Markets. Cornell University, Ithaca, NY.

Twarowska JG, Westerman PW and Losordo TM. 1997. Water treatment and waste characterization evaluation of an intensive recirculating fish production system. Aquacult Eng 16, 133-147.

Welch EB and Lindell T. 1992. Ecological effects of wastewater. Applied limnology and pollutant effects. Chapman and Hall, London, 76-81.

Wickins JF. 1980. Water quality requirements for intensive aquaculture: a review. Symposium on New Developments in the Utilization of Heated Effluents and Recirculation Systems or Intensive Aquaculture, EIFAC, 11th Session, Stavanger, Norway, 28-30 May 7-12.

(Received 25 March 2010; Revised 30 April 2010;
Accepted 15 June 2010)