Report for 2002HI1B: Removal of Nitrogenous Aquaculture Wastes by a Wind-Powered Reverse Osmosis System, Year 2

- Other Publications:
    - Liu, C.C.K.; J.W. Park, 2002, Water desalination, in McGraw-Hill Encyclopedia of Science & Technology, ninth edition, volume 22, New York, New York, McGraw-Hill, 404-406.
    - Liu, C.C.K., 2002, Wastewater reuse, in McGraw-Hill 2002 Yearbook of Science and Technology, New York, New York, McGraw-Hill, 406-409.
- Articles in Refereed Scientific Journals:
    - Qin, G; C.C.K. Liu; N.H. Richman; J.E.T. Moncur, 2005, Aquaculture wastewater treatment and reuse by wind-driven reverse osmosis membrane technology: A case study on Coconut Island, Hawaii, Aquaculture Engineering 32:365-378
    - Liu, C.C.K.; R. Migita; J.W. Park, 2002, System development and testing of wind-powered reverse osmosis desalination for remote Pacific islands, Journal of Water Science and Technology: Water Supply 2(2), 123-129.
    - Park, S.J.; C.C.K. Liu, 2003, Experimental and simulation of a wind-driven reverse osmosis desalination system, Water Engineering Research 4(1), 1-17.
    - Liu, C.C.K.; J.W. Park; R. Migita; G. Qin, 2003, Experiments of a prototype wind-driven reverse osmosis desalination system with feedback control, Desalination 150(3), 277-287.
- Dissertations:
    - Gang, Q., 2002, Cost-effective aquaculture nitrogen removal by wind-powered reverse osmosis membrane technology, MS thesis, Department of Civil and Environmental Engineering, College of Engineering, University of Hawaii, Honolulu, Hawaii, 186 pages.

Report Follows

Problem and Research Objectives

Advanced treatment must be provided to wastewater used for freshwater aquaculture in order to meet effluent water quality standards. Because such treatment can be expensive and because freshwater is also increasingly in short supply around the world, an attractive management alternative is to develop a closed aquaculture system that supports effluent treatment and reuse while overcoming obstacles of high treatment cost and a short freshwater supply. The research objectives for FY 2001 and FY 2002 are (1) to investigate the nitrogen build-up in freshwater aquaculture of tilapia, (2) to develop a wind-powered reverse osmosis (RO) nitrogen removal system, and (3) to evaluate the economic feasibility of the wind-powered RO system for removing nitrogen from aquaculture wastes.

The studies on removal of nitrogenous aquaculture wastes by a wind-powered RO system is followed by a second phase of research on a new pollution issue—namely, the discharged concentrate. The mechanisms of the RO membrane system are such that the discharge concentrate will have a higher nitrogen concentration level than that of the untreated wastewater from the fish tank. Thus the concentrate cannot be recirculated in the system; rather, it must be discharged or further treated before it can be reused. The research objectives for FY 2003 and FY 2004 are (1) to further investigate the nitrogen build-up in discharged concentrate from the RO system and (2) to develop a duckweed-based pond system to remove nitrogen from the concentrate.

Methodology

This began as a two-phase project, with each phase scheduled to last one year. The focus of the first year's research was to study the characteristics of aquaculture waste, especially the concentration of nitrogen at different stages of fish (tilapia) growth. The second year's research was to investigate the performance of nitrogen removal by the reverse osmosis process and to develop a water recirculating system for tilapia production.

The reverse osmosis module of the system separates the wastewater from the fish tank (or feed water) into permeate and concentrate. The high-quality permeate is circulated back to the fish tank and is reused as a freshwater supply. The concentrate is mixed with feed water and is treated again by the reverse osmosis module. As the system operation goes on, the nitrogen concentration in the concentrate becomes higher and must be discharged from the system. As part of the second phase of research, the desirable frequency of concentrate discharge is evaluated, and the process and reuse of waste concentrates by a duckweed-based reactor are investigated.

Principal Findings and Significance

An experimental system, which consists of an aquaculture subsystem or a fish tank for tilapia culture and a wind-powered reverse osmosis treatment subsystem, was constructed in FY 2001 at the research facilities of the Hawaii Institute of Marine Biology on Coconut Island, Oahu, Hawaii.

Water samples were collected from the tilapia culture tank from June 2001 to February 2002. Samples were analyzed in the water quality laboratory of the Water Resources Research Center at the University of Hawaii at Manoa. Table 1 shows the nitrogen concentration data for the aquaculture subsystem. Feedwater is the freshwater provided to the fish tank. Discharge indicates the aquaculture waste flow out of the fish tank. The waste discharge becomes the feedwater for the wind-powered reverse osmosis treatment subsystem. The hydraulic retention time in the aquaculture subsystem or fish tank was about 500 minutes (8.3 hours). During this time, the feedwater and waste discharge rates were both about 73 gal/h (4.6 l/min).

The feedwater provided to the fish tank contained ammonia nitrogen (NH_3-N) at a concentration of less than 0.03 mg/l, whereas the concentration in the aquaculture waste discharge averaged 0.20 mg/l with an unbiased standard deviation of ±0.12 mg/l. The average feedwater nitrate nitrogen (NO_3-N) concentration was 0.17 ± 0.02 mg/l, and the discharge concentration was 0.16 ± 0.02 mg/l. The nitrite nitrogen (NO_2-N) concentration was 0.0012 ± 0.0012 mg/l for the feedwater and 0.0019 ± 0.0015 mg/l for the discharge.

Performance of the reverse osmosis treatment subsystem to remove nitrogen has been evaluated by studying nitrogen concentrations in the feedwater and product water (permeate), as well as by studying the operating flow rate and feed water pressure. Preliminary data indicated that the subsystem removes about 93% of the ammonia and nitrate from the feedwater.

Table 1. Nitrogen Concentrations of Aquaculture Subsystem Under Normal Conditions

Date	NH_3-N (mg/l)		NO_3-N (mg/l)		NO_2-N (mg/l)	
	Feedwater	Discharge	Feedwater	Discharge	Feedwater	Discharge
06/13/2001	UD*	0.19	0.17	0.14	0.001	0.006
06/14/2001	UD	0.14	0.17	0.14	0	0.001
06/15/2001	UD	0.11	0.21	0.17	0.003	0.004
06/21/2001	UD	0.12	0.20	0.16	0.003	0.002
07/10/2001	UD	0.07	0.15	0.13	0.002	0.001
01/07/2002	UD	0.40	0.17	0.17	0.001	0.001
01/09/2002	UD	0.32	0.17	0.17	0.001	0.003
01/17/2002	UD	0.50	0.16	0.16	0	0
01/22/2002	UD	0.23	0.17	0.20	0	0.001
01/24/2002	UD	0.20	0.17	0.18	0.001	0.002
01/31/2002	UD	0.09	0.17	0.17	0.002	0.001
02/05/2002	UD	0.22	0.14	0.16	0	0.001
02/12/2002	UD	0.26	0.16	0.16	0.001	0.002
02/14/2002	UD	0.06	0.18	0.16	0	0.002
02/21/2002	UD	0.09	0.14	0.14	0	0
02/26/2002	UD	0.25	0.12	0.12	0.004	0.003

*****UD = undetectable.

Results of field experiments indicated that the frequency of concentrate discharge is one of the key factors that control the ammonia nitrogen concentration in the concentrate.

Figure 1 shows the changes of ammonia nitrogen concentrations in the feed water, permeate, and concentrate, with a 6-hour concentrate discharge frequency. Comparing the data presented for 4-hour and 8-hour discharging experiments, the peak ammonia nitrogen concentrations in concentrate from 6-hour discharges are 1.09 and 1.49 mg/l, and the peak nitrate concentrations in concentrate are 0.57 and 0.71 mg/l, which proves that the discharging period is a key factor in controlling the concentration levels of the concentrate discharged.

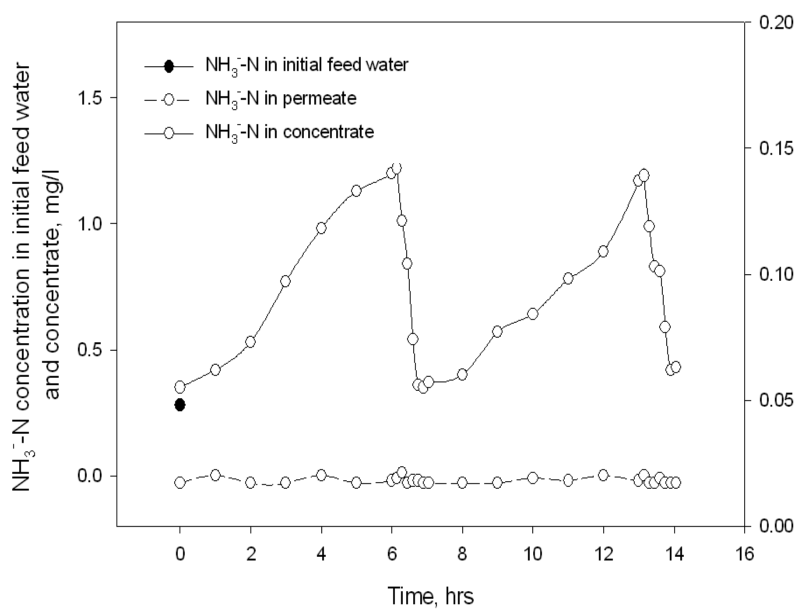

Figure 1. The concentration of ammonia nitrogen in the feed water in the permeate, as well as in the concentrate, with a 6-hour frequency of concentrate discharge and an average ambient wind speed of 5.3 m/s

Results of field experiments also indicated that the freshwater recovery rate would change with the frequency of concentrate discharge and the ambient wind speed (Figure 2).

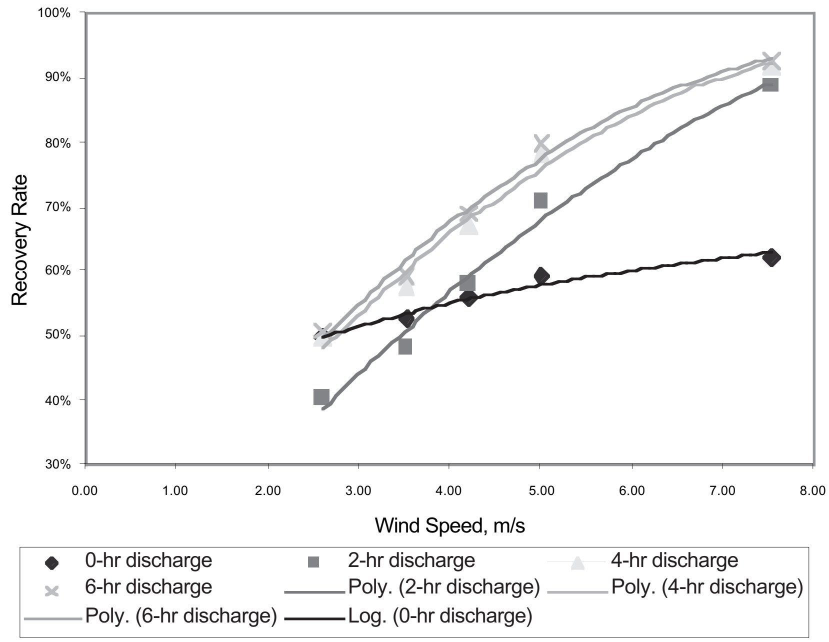

Figure 2. Relationships of freshwater recovery rate and ambient wind speed

A plug-flow bioreactor that was later constructed for the treatment and use of concentrate (brine) from the reverse osmosis process was tested (Figure 3).

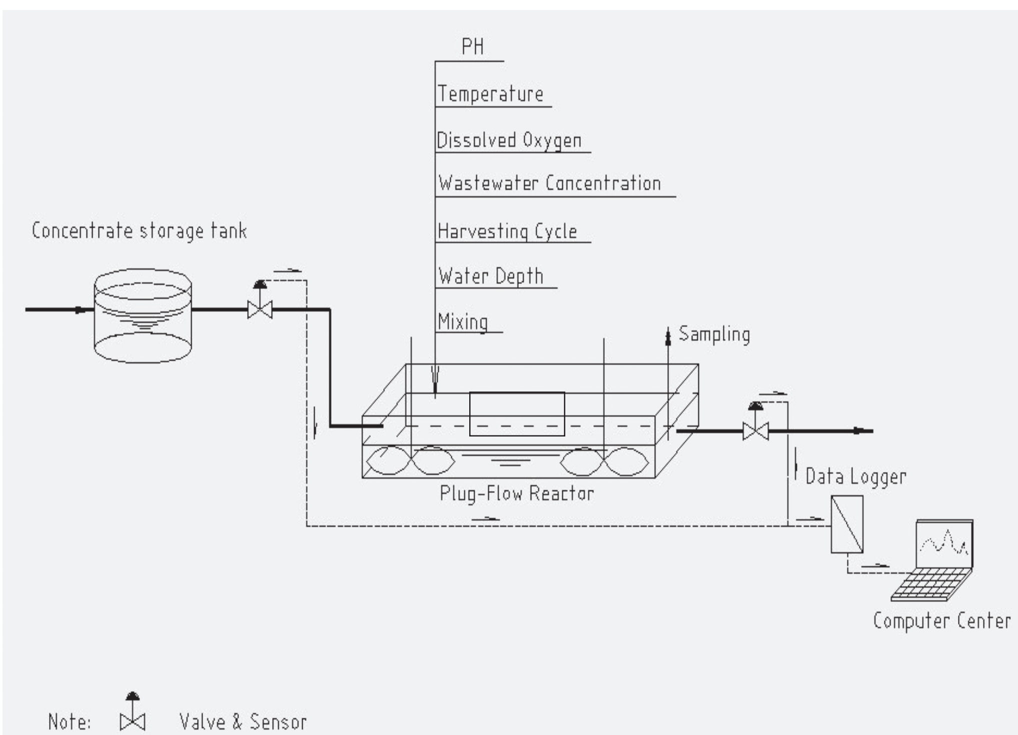

Figure 3. Schematic of plug-flow bioreactor

The system developed by this project can be added to a fishpond to form a closed aquacultural production system with zero waste discharge. The permeate (freshwater) from the system can be used as the freshwater supply for fish culture, while the brine (concentrated wastewater) can be further processed into fish feed by a duckweed-covered reactor.