Water Quality Management Efficiency of Biofilteration in a Recirculating Aquacultural System

[1]Onuegbu C. U., [2]Mbajiorgu C. C. and [3]Ezekafor S. C.

[1]Dept. of Agricultural Engineering Technology, Federal Polytechnic, Oko, Nigeria.
[2]Dept. of Agricultural/Bioresources Engineering, University of Nigeria, Nsukka, Nigeria.
[3]Dept. of Civil Engineering, Anambra State University, Uli, Nigeria

Corresponding author: E-mail - caesero1000@yahoo.com

Abstract
One of the major challenges of recirculating aquaculture technology is the maintenance of water parameters at levels safe for the healthy growth of the aquatic life being reared. A biofilter is an indispensable component of a recirculating aquacultural system (RAS). It improves the biochemical qualities of the system water for re-use. In this study a fully designed and constructed recirculating aquacultural system was stocked with eighteen thousand catfish fingerlings and run for one complete rearing cycle of seventeen weeks using plastic as the biofilter media. Total ammonia nitrogen (TAN) concentration of the system was measured at the inlet and outlet points of the biofilter during the culture period. The results indicated that for the untreated water, the concentration showed a general increase through the culture cycle while for the treated water there was a marked drop in concentration values for the first four weeks, followed by a fairly constant value for the rest of the period. These values for the treated water were significantly ($p < 0.05$) below the critical value for safe fish culture. The maximum TAN value obtained for the untreated water was 12.770×10^{-1} mg/l, while that for the treated water was 4.226×10^{-1} mg/l. The minimum TAN values were 6.214×10^{-1} mg/l and 1.396×10^{-1} mg/l for the treated and untreated water respectively. Statistical analysis indicated significant ($p < 0.05$) difference between TAN values for treated and untreated water. Based on the TAN concentrations of inflow and outflow of the trickling filter, its efficiency was determined over time and result showed that the plant reached at average efficiency of 79% in three weeks, having started with an efficiency of 32% at the beginning of operation.

Key words: Biofilteration, Water quality, Recirculating Aquacultural System, Management efficiency, Catfish fingerlings

Introduction
Over the ages, fish has been and will continue to be, a major source of protein for mankind. The global demand for fish, Nigeria inclusive, has remained greatly unsatisfied due, partly, to:

- Direct increases in the per capita consumption of seafood which, according to Pfeiffer (2010), has continued to increase in United States and throughout the world. Here in Nigeria, Adeyemi (2011) reported that the annual fish demand was 2.66 million, as against annual production of 0.78 million metric tones, resulting in a shortfall of 1.88 million metric tones annually; and that the country spent over N100 bn on the importation of frozen fish in 2010 alone.
- Decreases in fish catch from surface water bodies (seas, rivers, lakes, oceans etc.) as a consequence of the discharge, into these waters, of increasing amounts of noxious and toxic wastes and pollutants from increasing industrial, agricultural and other human activities. These substances alter the water parameters that promote healthy fish culture and therefore drastically affect fish growth.

The above scenario underscores the need to double efforts at fish farming. Vast stocks of highly nutritive and healthy fish can conveniently be cultured in ponds requiring small spaces. However, since fish live and perform all their body functions in water, and they are sensitive to water quality, the success or failure of an aquacultural system depends on operation the quality as well as quantity of water in use (Chem et al, 1997; and Malone, 1992).
In an artificial commercial fish culture, there is a high build- up of biological wastes which progressively affect the water quality (dissolved oxygen, pH, ammonia and nitrite concentrations etc.) that is necessary for healthy fish growth (Delos Reyes Jr., 1998). The aim of this study was to determine the efficiency of a trickling filter water treatment in a recirculating aquaculture system. The specific objectives were to determine the total ammonia concentrations of the influent and effluent water and thereby evaluate the performance efficiency of the trickling filter treatment in a given system (Onuegbu, 2011).

Theory of RAS

A recirculating aquaculture system (RAS) is defined as an assemblage of parts and devices used for husbandry of aquatic organisms in which water is continuously cleaned and recycled. Recirculating aquaculture systems are more complex in design and operation than any of the other systems. Their advantages over the other aquacultural production systems include:

- Environmental conditions (water temperature, salinity, etc.) can be fully tailored to optimally fit the requirements of the fish of interest, thus ensuring optimal performance and the fastest growth rates to market size. As such recirculating systems are generic and can be modified to accommodate the species for which the market feasibility is highest.
- They are designed to use sustainable high quality water sources with no contaminants, toxins or off-flavor sources.
- They promote better feed conversion ratio, year-round production, consistency of product quantity and quality, reduced water usage and control of market time and size.
- Recirculating aquaculture facilities are fully contained and thus can be located almost anywhere. Site selection is not dictated by proximity to a natural source of water such as lakes, rivers or ocean, but rather by the business opportunity.

The major challenge in Recirculating Aquacultural Technology is the design, construction and maintenance of an efficient plant capable of maintaining the system water parameters at optimal levels for healthy fish growth over time. Some of these parameters such as total suspended solids (TSS) and dissolved oxygen (DO) are physical while others, such as ammonia concentration, are biochemical. A desirable treatment plant for RAS should therefore incorporate both physical as well as biological treatment units as in Figure 1.
The biochemical factors of the culture water pose greater problems than the physical factors because they affect the general life of the fish much more adversely. The success or failure of a RAS is therefore largely dependent on the efficiency of the biological treatment in place. Various types and designs of biofiltration media are in use today. These include but

are not limited to stone, bead and plastic. In this study a trickling filter was used as the biological filter and its efficiency was monitored over time on the basis of reduction of the ammonia concentration in the system water.

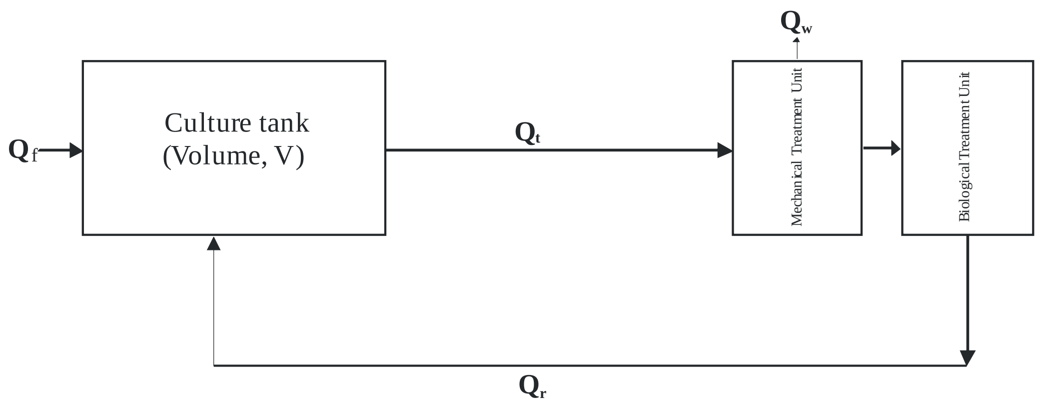

Figure 1: Schematic Diagram of a Recirculating Aquacultural System

The symbols in the diagram are defined as follows:

$Q_{t.}$ = Tank outflow; Q_f = Tank inflow; Q_r = Recycle flow; Q_w = Wastewater discharge.

Methodology

A newly constructed commercial recirculating aquaculture system was used for this study (Onuegbu, 2011). The system was made up of two sections, the fish culture section and the waste water treatment section, integrated into a whole unit with a network of PVC pipes.

The fish culture section consisted of culture tanks connected in parallels by means of PVC pipes. On the other hand the wastewater treatment section was made up of two major units, the particulate removal unit and the biological treatment unit. The particulate removal unit which removes suspended solids from the system water consists of a foam fractionator skim and a sedimentation tank. On the other hand, the biological treatment unit, (the biofilter or trickling filter) which is the focus of this study, reduces ammonia load of the system water to levels safe for healthy fish growth.

Ammonia is the major end product in the breakdown of proteins in fish. Fish digest the protein in their feed and excrete ammonia through their gills and in their feces. Ammonia also enters the pond from bacterial decomposition of organic matters such as uneaten feeds, dead algae and aquatic plants (Durborow et al, 1997). Two forms of ammonia occur in aquaculture systems.

- Ionized ammonia (NH_4^+)
- Un-ionized ammonia (NH_3).

The un-ionized form of ammonia is extremely toxic while the ionized form is not. Both forms are grouped together as total ammonia nitrogen (TAN), Durborow et al (1997). The relationship between the two is indicated in Equation 1 below.

$$H^+ + NH_3 \rightleftharpoons NH_4^+ \qquad (1)$$

The ammonia removal action of the biofilter is a two stage bacterial process. The first stage involves the breakdown of ammonia to nitrites by a group of bacteria known as nitrosomonas bacteria while the second stage is a further breakdown of nitrites into non-toxic nitrates by nitrobacter bacteria. The biochemical quality of the recirculating water and, by implication, the efficiency of the biofilter is therefore a measure of the capacity of the biofilter to reduce the total ammonia nitrogen load of the system water for reuse.
The culture tanks were stocked at a density of 300 fishes per cubic meter of water, and the biofilteration chamber was loaded with plastic trickling filter media in accordance with the design calculations. Other sections of the RAS were also taken care of as necessary. The system was then run for one complete rearing cycle of seventeen (17) weeks and the TAN variations of the system water were monitored on daily basis at the inlet to, and outlet from the biofilter. The differences in the TAN values at these two points were further subjected to a simple statistical analysis for significance using the **t-test** which yielded:

$$df = (17 - 1) = 16 \quad (2)$$
$$t_{cal} = 14.378$$
$$t_{tab} = 2.120.$$

Again on the strength of the data obtained, the performance (efficiency) of the trickling filter was determined. The results obtained are shown and discussed below.

Results

Total Ammonia Nitrogen (TAN) Concentrations

Total ammonia nitrogen concentrations were measured for both the influent and effluent water. The weekly averages of the results obtained are presented in Figure 2.

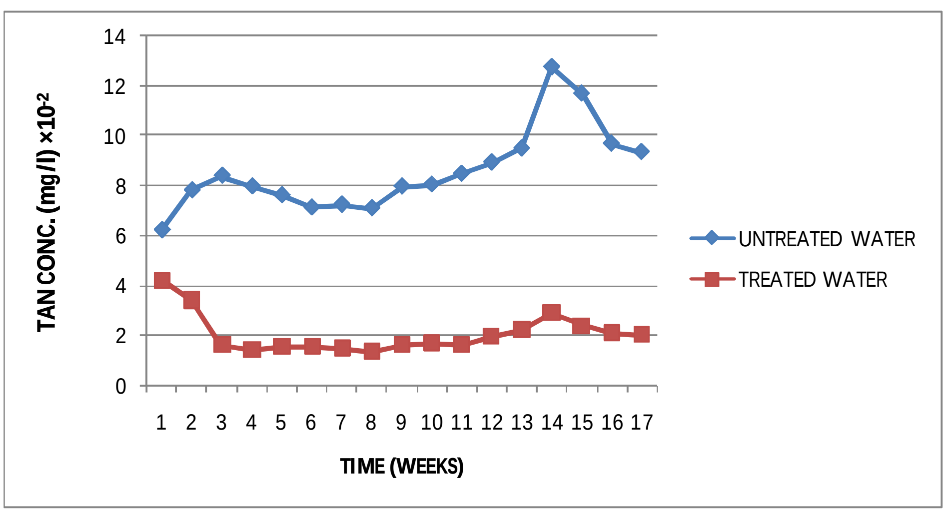

Fig. 2: Average Weekly TAN Concentration (mg/l)

Treatment Plant Efficiency

The efficiency of the treatment plant was calculated based on the average weekly values of total ammonia nitrogen concentrations of both treated and untreated water throughout the production cycle. The results obtained are shown in Fig. 3.
The efficiency of the treatment plant was assessed using its ability to remove TAN from the culture water. The efficiency was calculated using the expression:

$$E_P = \underline{TAN_u - TAN_t} \qquad (3)$$

where:

E_p = Plant efficiency
TAN_u = TAN concentration of untreated water
TAN_t = TAN concentration of treated water

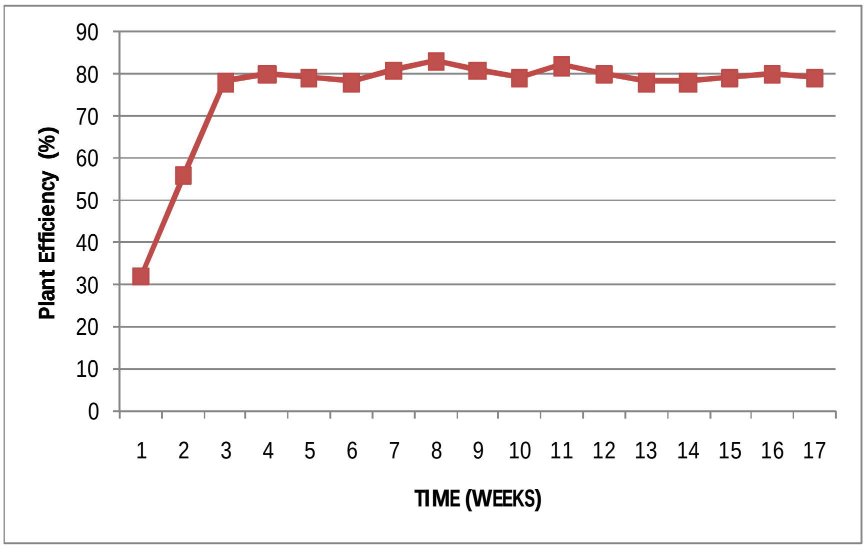

Fig. 3: Plant Efficiency during the culture period.

Discussions of Results

Variation in Total Ammonia Nitrogen (TAN) Concentration.

The results obtained for TAN of both the influent and effluent system water are presented on Fig. 2.
The following can be deduced from these results:

- A steady rise in TAN concentration of the untreated (influent) water indicating a sustained increase in waste generation, with time, by the fish.
- An initial increase, followed by a sustained drop, in TAN concentration of the effluent (treated) water, indicating a time lag before the biofilter started working at its optimum efficiency.
- A widening difference between successive corresponding TAN concentration values for the untreated and treated waters, indicating increasing efficiency of the treatment plant with time.
- Since $t_{cal} > t_{tab}$, the TAN values for treated and untreated water were significantly different.

Treatment Plant Efficiency

The result presented in Fig. 3 shows that it took three weeks for the plant to attain an average operating efficiency of 79%, having started in the first week with an average performance efficiency of 32%. The first four weeks seemed to be the period of the buildup of the nitrifying bacteria in the biofilter.

Conclusion

The very high efficiency achieved by the trickling filter in this study indicates that the RAS system water was very effectively cleansed of biochemical wastes (ammonia) before being recycled to the culture tanks, thus providing a suitable environment for healthy fish production.

Although the initial costs of procurement and installation of plastic trickling filter media are high, they are strongly recommended for use in recirculating aquacultural systems based on the results of this study.

References

Adeyemi, Frederick. 2011. Environmental Friendly Aquaculture Key to Sustainable Fish Farming Development in Nigeria Continental Journal of Fisheries and Aquatic Sciences, 5 (2): 17-31

Chem, S., Caffin, D.E., and Malone, R.E. 1997. Sludge Production and Management for Recirculating Aquacultural Systems. Journal of World Aquaculture Systems, 28 (4): 303 - 315.

DeLosReyes Jr. A. A., Rusch, K.A. and Malone, R.F. 1998. Generation and Management of Waste Water in an Alligator Farm. Journal of Applied Aquaculture, 8(2): 27 - 38.

Onuegbu, C.U. 2011. Design, Construction and Testing of a Recirculating Aquacultural System for Intensive Fish Production. Unpublished M.Eng. Degree Thesis. Department of Agricultural and Bioresources Engineering, University of Nigeria, pp. 89

Pfeiffer, T. 2010. Recirculating Technology: The Future of Aquaculture Resource vol.17, No 3. American Society of Agricultural and Bioresources Engineers (ASABE) Publication.