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Estimation of flow rate and sizing of trickling filter in a recirculating aquaculture system

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ABSTRACT : In a recirculating aquaculture system (RAS), waste is generated from uneaten feed, fish faecal matter and organic debris from dead and dying organisms. These wastes generally decompose to produce mainly nitrogenous compounds in the form of ammonia, nitrite and nitrate. These nitrogenous compounds are particularly important in intensive RAS because of their toxicity to culture organisms. Therefore, removal of these compounds is very much necessary for successful operation of RAS. Adsorption, ion exchange and biological filtration are the three major available options for removal of nitrogenous wastes. In the first two options, frequent regeneration of media is required which usually increases the cost of the operation. Therefore, in the present study biological filtration has been chosen an option for aquaculture wastewater treatment. In the present study proper sizing of biofilter based on mass balance approach has been presented which is of critical importance to the successful design of any recirculation system.

KEY WORDS : Recirculation system, Nitrogenous compounds, Biological filtration

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The accurate estimation of water recirculation flow rate and appropriate sizing of nitrifying biofilters are of critical importance to the successful design of any recirculation system. An approach for sizing of biofilter based on nitrification rate is outlined by Losordo and Hobbs (2000). The partial water exchange is allowed to maintain the level of nitrate–nitrogen concentration in the rearing tank within the permissible limit. As aquatic animals are quiet sensitive to water quality parameters, it is decided to fix the permissible limit for NO_3–N concentration at 20 mg/L. Based on this criterion, a mass balance approach is adopted to determine the water flow rate requirement for the RAS under consideration.

METHODOLOGY

Flow rate estimation :

The desired recirculation flow rate is selected as the highest of the flow rates obtained using the mass balances for total ammonia nitrogrn (TAN), dissolved oxygen (DO) and suspended solids (SS). The recirculation flow rate is to be calculated using various inputs and assumptions as provided in Table A.

Based on the above inputs and assumptions, mass balances of TAN, DO and SS were carried out to determine the required recirculating flow rate.

The desired recirculation flow rate was selected as the highest of the flow rates obtained using the mass balances for TAN, DO and SS.

Table A : Various inputs and assumptions for calculation of recirculation flow rate

Sr. No.	Parameters	Notation	Amount/ Quantity/ Concentration	Unit	Remarks
Inputs					
1.	Harvested fish biomass	W_h	8.5	kg	500 numbers of fish harvested with an average weight of 17 g
2.	Feeding rate	R_f	2.5	%/day	(Penry and Jumars, 1986)
3.	Water pH	pH	7.6	–	Wheaton *et al.* (1994)
4.	Water temperature	T	27	^oC	25–30 ^oC
5.	Influent SS concentration	S_i	2	mg/l	Measured
6.	Percentage of protein in fish feed	P_f	33	%	(Penry and Jumars, 1986)
7.	Percentage of nitrogen in protein	N_f	16	%	(Penry and Jumars, 1986)
Assumptions					
1.	Percentage amount of feed waste	F_w	70	%	(Lawson,1994)
2.	Percentage of nitrogen in waste feed generating total ammonia nitrogen	N_w	85	%	(Lawson,1994)
3.	Desired concentration of SS	S_d	15	mg/l	(Malone and DeLos Reyes, 1997)
4.	Perm. DO conc. in rearing tank	DO_p	5	mg/l	(Boyd, 1982)
5.	Perm. DO conc. at biofilter outlet	DO_{bo}	2	mg/l	(Lawson,1994)
6.	Biofilter eff. for TAN removal	E_b	23	%	Generally efficiency lies between 25–30%
7.	Screen filter efficiency	E_{mf}	30	%	Assumed (Losordo *et al.*, 1998)
8.	Foam fractionator efficiency	E_{cf}	15	%	Assumed (Brambilla *et al.*, 2008)
9.	Perm. Conc. of NH_3–N	$(NH_3–N)_p$	0.025	mg/l	(Lawson, 1994)
10.	Percentage of feed becoming solid waste	A	30	%	(Westers, 1995)
11.	Oxygen required (g) for fish respiration per kg of feed applied	K_{oxy}	300	g/kg	(Lawson, 1994)
12.	Oxygen required (g) for nitrifying bacteria per kg of feed per day	K_{BOD}	2.16	g/kg/day	(Lawson, 1994)

Note: "Perm.", "conc.", "eff." and "SS" denote "permissible", "concentration", "efficiency" and "suspended solid" respectively.

TAN mass balance :

The production rate of TAN (PR_{TAN}) can be calculated using the following equation (Lawson, 1994):

$$PR_{TAN} = W_h \times R_f \times P_f \times F_w \times N_f \times N_w \times 1000 \quad \ldots (1)$$

The recirculation rate based on the mass balance analysis of TAN (Q_{rTAN}) can be expressed as follows:

$$Q_{rTAN} = PR_{TAN}/[(TAN)_p \times E_b] \quad \ldots (2)$$

Permissible TAN $(TAN)_p$ is a direct function of $(NH_3–N)_p$, pH and temperature (T) of water and can be calculated from the following equation (Emerson *et al.*, 1975).

$$(TAN)_p = (NH_3–N)_p \times [1+10^{\{0.09018+(2729.92/(273+T)\}–pH}] \quad \ldots (3)$$

DO mass balance :

The required production rate of DO (PR_{DO}) in the RAS was found out by taking mass balance of DO across the RAS as follows (Lawson, 1994):

$$PR_{DO} = \text{Total oxygen demand in the RAS} \quad \ldots (4)$$
$$= CR_{Fish} + CR_{BOD} + CR_N$$

where, CR_{Fish}, CR_{BOD} and CR_N are oxygen demand by fish, carbonaceous oxygen demand and oxygen demand for nitrification, respectively.

CR_{Fish}, CR_{BOD} and CR_N can be calculated using the following equations:

$$CR_{fish} = K_{oxy} \times R_f \times W_h \quad \ldots (4a)$$

Wimberley (1990) reported the biofilter oxygen demand about 2.3 times the BOD production rate.

Therefore,

$$CR_{BOD} = 2.3 \times K_{BOD} \times W_h \times [(1 – E_{mf}) \times (1– E_{cf})] \ldots (4b)$$

USEPA (1975) reported that for every gram of TAN oxidized to nitrate, 4.57 g of DO consumed.

Therefore,

$$CR_N = 4.57 \times PR_{TAN} \quad \ldots (4c)$$

To fulfill the above oxygen requirement in the rearing tank, the chosen air pump described as (Make: Resun ACO–003; Pressure: 0.027 MPa; Power: 35 W; Voltage: 220–240 V~ 50 cycles; Output: 0.065 m^3/minute and Depth of operation: 1.0 m.) was found to be adequate. The field oxygen transfer rate (OTR) of the air pump was found to be 129 g/day which was more than the required amount. Recirculation flow rate required to maintain DO (Q_{rDO}) was found out by taking mass balance across the biofilter as follows:

$$Q_{rDO} = [CR_{BOD} + CR_N] \times [(1 - E_{mf}) \times (1 - E_{cf})]/[(DO)_p - (DO)_{bo}] \quad \ldots(5)$$

Suspended solid mass balance :

Recirculation flow rate required to maintain SS (Q_{rss}) was found out by taking mass balance across the entire RAS as follows:

$$Q_{rss} = [(PR_{SS}) \times (1 - E_{mf})] / [S_d \times E_{cf}] \quad \ldots(6)$$

where, PR_{SS} = Production rate of suspended solids …(6a)

$= \alpha \times W_h \times R_f \times 1000$

■ RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Recirculation flow rate :

The proper recirculation flow rate is very much important for successful operation of any reciruclating aquaculture system. Too slow recirculation flow rate leads to increase in suspended solids so that the biofilter gets chocked and too much recirculation flow rate leads to less time of ponding of water in biofilter. In both the cases nitrification rate and nitrogen removal efficiency of biofilter gets affected. Therefore, in the present study the desired recirculation flow rate was selected as the highest of the flow rates obtained using the mass balances for three most important water quality parameters for growth of fish viz., TAN, DO and SS.

TAN mass balance :

The production rate of TAN (PR_{TAN}) in the system can be obtained by considering eq. 1

PR_{TAN}= 8.5 x 0.025 x 0.33 x 0.70 x 0.16 x 0.8 x 1000 = 6.68 g/day

Substituting the values of T and pH as 27°C and 7.6, respectively, the value of $(TAN)_p$ considering equation 3 becomes 1.0 mg/l.

Thus, the recirculation flow rate was obtained by considering eq. 3 as:

Q_{rTAN} = 6.6 / (1 x 0.23) = 28.7 say 29 m^3/day.

DO mass balance :

Substituting the values of K_{oxy}, K_{BOD}, W_h, E_{mf}, E_{cf} and PR_{TAN} in equation 4,4a, 4b and 4c,the production of DO (PR_{DO}) can be obtained as:

PR_{DO} = 300 × 0.025 × 8.5 + 2.3 × 2.16 × 8.5 × (1–0.3) × (1–0.15) + 4.57×6.68

= 119 g/day

Thus, recirculation flow rate required to maintain DO (Q_{rDO}) was found out by considering eq. 5

Q_{rDO} = [(2.3 × 2.16 × 8.5 + 4.57× 6.6) × (1–0.3) × (1–0.15)]/ (6–2)

= 13.9 m^3/day.

Suspended solid mass balance :

Substituting the values of α, W_h, R_f, E_{mf}, S_d and E_{cf} in eq. 6 and 6a the recirculation flow rate obtained considering suspended solids mass balance approach in the system as follows:

Q_{rss} = 0.30 × 8.5 × 0.025 × 1000 × (1–0.3)/ (15 × 0.15) = 19.8 m^3/day

It can be observed that the required flow rate of 29 m^3/day obtained in TAN mass balance is the highest among the other flow rates. Therefore, the recirculation flow rate was chosen as 29 m^3/day.

Trickling filter sizing :

The nitrification rate (NR) of trickling filter varies in between 0.2 – 0.4 g TAN / m^2/day (Parker *et al.*, 1995). In the present study, a conservative value of 0.2 g TAN / m^2/day was assigned for the nitrification rate of trickling filter. The active nitrification surface area required and volume of filter media required in the trickling filter were found out using the following equations:

Active surface area required for nitrification (A_s) = PR_{TAN}/ NR … (7)

= 6.68 / 0.2

= 33.4 m^2 say 34 m^2.

Total volume of filter media required (V_t) = A_s/ A_{ss} … (8)

= 34 / 1213

= 0.028 m^3 say 0.03 m^3

where, A_{ss} is specific surface area of filter media (m^2/m^3).

Further assuming 3 numbers of trickling filters and effective depth of the trickling filter *i.e.*, depth of filter media (d_m) as 1.6 m, cross–sectional area of trickling filter

$(A_{tf}) = V_t / d_m$ … (9)

$= 0.03\ m^3 / 1.6\ m = 0.018\ m^2$.

diameter of trickling filters (D) = $[4 \times A_{tf} / (\text{No. of trickling filters} \times \pi)]^{1/2}$ … (10)

$= 0.09$ m.

Based on the above calculations, the design dimensions of the trickling filters were selected as follows:

Design dimensions :

Material : Acrylic column; Media: Nylon pot scrubber; Diameter: 90 mm Height = 1600 + 200 mm (freeboard) = 1800 mm and number of trickling filters: 3

Fabrication of trickling filter:

Three cylindrical acrylic columns of diameter 90 mm and height 1800 mm were fabricated. An air pump was provided at the bottom of all the columns with diffuser air stones. A water spraying mechanism was also provided for uniform distribution of effluent over the top surface of the columns.

Conclusion :

Therefore, it can be concluded that proper selection and sizing of biofiltration units are essential for both technical and economical success of the process. Moreover, the technique of recirculating aquaculture system offers a scope for ecologically sustainable fish production. This technique is very much effective in commercial aquaculture sector (Tanveer *et al.*, 2016). The required recirculation flow rate of 29 m^3/day was calculated to run the system. Nylon pot scrubber, with a specific surface area of 1213 m^2/m^3, is found to be very much effective as a media for the growth of bacteria and removal of toxic nitrogenous nutrients.

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