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Full Length Article

Feed Dosage and Ammonium Control Device Based on C/N Ratio for a Zero-Discharge System

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ABSTRACT

In intensive aquaculture, one solution to water use efficiency is to add carbohydrates (CH) to the system, in order to develop a bacteria population able to process the inorganic nitrogen produced by the un-eaten food and fish excretion. This method has been tested in the past few decades, proving to be a very efficient solution for water treatment *in situ*. Fish are poikilothermic vertebrates and their feeding rate varies according to temperature. As a result, food and CH dosage must be carefully calculated in conditions where the water temperature cannot be controlled. This paper presents the development, implementation and testing of a low cost system of feed dosage and ammonium control device (FDACD) based on C/N ratio, through the CH addition, that considers temperature to dose feed in an aquaculture system, controlling the total ammonium nitrogen (TAN) flux to maintain the tank with "zero discharge", heightening the profitability and contributing to solve the aquaculture sustainability problem.

Key Words: Water use efficiency; TAN; Carbon/Nitrogen; Temperature; Dose control

INTRODUCTION

Water use in aquaculture is a problem of sustainability, since it is an industry that produces a great waste volume, generating problems regarding the environment (Dewedar *et al*., 2006), society and the hydric resource *per se*. This situation sets the need of applying water efficiency use. Efficiency means to obtain a higher production by using less water, solving the principal problem in aquaculture systems: the accumulation of toxic inorganic nitrogenous species (NH_4^+ & NO_2^-) in water (Masser *et al*., 1999). This problem begins with an incorrect feeding, since often the provided food amount is inappropriate, leading to a process, where the un-eaten food decomposition consumes oxygen and produces ammonia-nitrogen (Chang *et al*., 2005).

Avnimelech (1999) presented a work regarding the utilization of microbial protein, where the water treatment was based on developing and controlling heterotrophic bacteria within the culture component. Bacteria utilize uneaten food and uptake inorganic nitrogen from the water to produce microbial protein in systems where the C/N ratio is high. This is made through CH addition, reducing the inorganic nitrogen concentration of intensive aquaculture systems. Nutrients are recycled, doubling the protein use and raising feed utilization. Similar results in other animals are shown in Salman *et al.* (2008). These tanks must be aerated and mix to improve the efficiency in this process, oxygen concentration is considered high (>5 mg L^{-1}), with this condition, the fish growth performance depends directly on water temperature (Avnimelech, 2006), which also influences the feed intake; so, the food biomass percentage must be adapted according to the temperature changes. If the food quantity is changed, the TAN concentration will change as a function of the feeding rations. That means, the carbohydrate (CH) amount must be adjusted to neutralize the TAN produced by the food added to the tank and fish excretion; this factor is clearly variable, hence, the CH amount should be strictly controlled. This work presents the development, implementation and testing of a feed dosage and ammonium control device (FDACD) based on C/N ratio, which monitors and considers the water temperature to dose food and considers the ammonium flux to add CH, to keep the tank with "zero discharge".

MATERIALS AND METHODS

The experiments were carried out at the Universidad Autónoma de Querétaro (Queretaro State University, Mexico) in the fish farm named AQUA-UAQ from April 4th to 18th, 2007. This fish farm is under a polyethylene greenhouse, whose area is 672 m^2 (24 m x 28 m). In the greenhouse there are twelve circular tanks with 20 m^3 water volume each one. The tanks are made of 20 mils thick black high density polyethylene; water level in the tanks is 1.0 m.

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A continuous aeration system was installed using stone diffusers and a blower of 2.5 HP; the aeration system was calculated to keep the dissolved oxygen concentration up to 5 mg/l.

Each tank was stocked with two thousand tilapias (*O. niloticus)* with an average weight of 20±3 g. One month previous the fish were put into the tank, the water was prepared by keeping a continuous water flow in order to achieve the desired bacteria population. FDACD - TUNA^{TM} system managed feed and CH dosages through a feeder and dosage pump, considering water temperature measured on-line. The schematic diagram system is shown in Fig. 1. Fish feeding was made by using an automatic feeder which doses depend on the feeding times per day and the water temperature. The parameters input and feeding criterion input are shown in Table I and Table II, respectively; that feeding criterion was established according with previous studies published by Buentello *et al*. (2000). Commercial tilapia floating diet pellet size of 1.5 mm containing 45% protein, 16% fat, 2.5% fiber and 12% ash, was used for fish feeding. One tank was used to probe the device with three replicates.

Temperature and pH were monitored on-line; the 7817 sensors (Davis Instruments, USA) and a WQ201 pH sensor (Global Water, USA) were used. The measures were collected via the data acquisition system and dispatched to the FDACD - TUNA^{TM} system that release the activity control in the aquaculture system. Ammonium measurements (TAN, toxic component, NH_3) were collected once a day employing the Hach Method 8038, using a DR/2400 portable spectrophotometer (HACH, USA) to verify the effectiveness estimation system.

Development of the Control and Software Device (FDACD)

CH Estimation. The criterion on CH dosage was based on Avnimelech (1999), where the amount of CH addition needed to assimilate the ammonium flux into microbial proteins is calculated with Eq. (1):

$$\Delta CH(g) = \frac{feed(g) \times \%Nfeed \times \%Nexcretion}{\%C \times E / (C/N)_{mic}} \qquad (1)$$

Where ΔCH is the CH amount in grams (g), *feed* is the amount of food supply needed, according to the total biomass and the daily feed rate, *%Nfeed* is the amount of nitrogen in the food obtained by *protein_percentage/645*, *%Nexcretion* is the ammonium flux into the water, *%C* is the carbon content of the added CH, *E* microbial conversion efficiency and $(C/N)_{mic}$ is the ratio in the microbial biomass. The *%Nexcretion*, *%C*, *E* and $(C/N)_{mic}$ are considered 0.5, 0.4, 0.4 and 4, respectively. Detailed calculus information is presented by Avnimelech (1999).

Software development for the control device. The software was developed in Turbo C++ and run under FreeDOS in a regular personal computer that practically are considered waste in office works (PC's from 386 processors) in order to maintain the low cost of the system. The FreeDOS is a mono-user and mono-task system, where the processor is exclusively dedicated to execute the process. The graphic interface was developed with a driver's video of 8 bits. The main functions of this software are: (a) to supply the food and CH dosages by means of the feeder and the dosage pump according with the water temperature and TAN flux; (b) to develop a data base containing water temperature and pH values, saved each five minutes; and (c) to record the food and CH historical dosages. Fig. 2 shows the main screen, which contains the general system information, such as: volume of the tank in litres (l), biomass in kilograms (kg), daily feed rate in biomass percent (%), percent of protein content in food (%), optimal food and CH dosages, in grams and seconds respectively; CH concentration (kg/l), state of actuators (green/red circle color, ON/OFF state of the feeder & pump), listing of dosages number, feeding hour (H), food amount (g), CH dosage (g), temperature (ºC); the temperature and pH measures on line are shown too. Each line is crossed out after the operation it represents is performed. A clock is also shown in top right corner of all screens. In this screen three squares are shown, program (F1), graphics (F2) and criterion (F3); the F's are the function keys on the keyboard and their function is modify the general system information, display graphics and modify the dosage criterion data. The software calculates the listing of dosages number considering the start feeding time, the stop feeding time and the dosage per day by means of the Eq. (2) and Eq. (3).

$$dosage\_time(h) = \frac{stop\_feeding - start\_feeding}{dosage\_per\_day - 1} \qquad (2)$$

$$listing\_dosage\_number = \begin{cases} start\_feeding & when\ time = start\_feeding \\ start\_feeding + dosage\_time & when\ time > start\_feedin \end{cases} \qquad (3)$$

Then, with the biomass, daily feed rate and dosage per day it calculates the food amounts that must be deliver in each feeding time, using the Eq. (4):

$$feed(g) = \frac{biomass(kg) \times daily\_feed\_rate(\%) \times 10\left(\frac{g}{kg}\right)}{dosage\_per\_day} \qquad (4)$$

The ΔCH and *feed* are calculated with Eq. (1) and Eq. (4), respectively. These dosages represent the 100% of the food and CH amounts that would be added in optimal water temperature conditions, these amounts represent the optimal food and CH dosages that appear in the main screen. When one of the dosages time is fulfilled, the software takes the water temperature (*Temp*) and according with the feeding criterion (*dosage_factor*) established in Eq. (5), modifies the optimal food and CH amounts that must be now added to the system, Eq. (6). In Eq. (5), t´s (t_1 to t_6) and f´s (f_1 to f_6) determinate the temperature and feeding ranges, where the user program the feeding criterion input, depending on the temperature conditions of the system in each feeding time.

$$dosage\_factor=\begin{cases} f_1 & when\ Temp<t_1 \\ \dfrac{(f_2-f_1)(Temp-t_1)}{t_2-t_1}+f_1 & when\ t_1\leq Temp<t_2 \\ \dfrac{(f_3-f_2)(Temp-t_2)}{t_3-t_2}+f_2 & when\ t_2\leq Temp<t_3 \\ \dfrac{(f_4-f_3)(Temp-t_3)}{t_4-t_3}+f_3 & when\ t_3\leq Temp<t_4 \\ \dfrac{(f_5-f_4)(Temp-t_4)}{t_5-t_4}+f_4 & when\ t_4\leq Temp<t_5 \\ \dfrac{(f_6-f_5)(Temp-t_5)}{t_6-t_5}+f_5 & when\ t_5\leq Temp<t_6 \\ f_6 & when\ Temp\geq t_6 \end{cases} \quad (5)$$

$$\begin{aligned} food\_dosage &= optimal\_food\_dosage \times dosage\_factor \\ CH\_dosage &= optimal\_CH\_dosage \times dosage\_factor \end{aligned} \quad (6)$$

With the food and CH amounts, the time that the feeder and the pump must be switched is calculated in seconds, by means of the feeder and pump fluxes, along with the CH concentration, using Eq. (7) and Eq. (8):

$$optimal\_food\_dosage(s)=\frac{feed(g)\times 60\left(\frac{s}{\min}\right)}{flux\_feeder\left(\frac{g}{\min}\right)} \quad (7)$$

$$optimal\_CH\_dosage(s)=\frac{\Delta CH(g)\times 60\left(\frac{s}{\min}\right)}{CH\_concentration\left(\frac{kg}{l}\right)\times 1000\left(\frac{g}{kg}\right)\times flux\_pump\left(\frac{l}{\min}\right)} \quad (8)$$

The software uses the computer serial port to switch the actuators that, in this case, is a pump to add the CH diluted in water and a feeder motor to supply the food. The communication between the computer and actuators is wireless. In this case, the computer uses a transmitter and each actuator uses a receiver, since the actuators do not have to send any data to the computer. Each receiver has a power interface integrated to switch the actuator. The actuators are controlled by time. This process is performed each feeding time.

RESULTS

The temperature variation changes the food amount supplied by the FDACD according with the feeding criterion shown in Eq. (5), therefore, the CH amount should also be changed in each feeding time. This action is performed by the control system installed in each production tank. The food ration and CH dosages are shown in Fig. 5 and 6. As it can be seen, the controller function was performed correctly during the process test. These results lead to the conclusion that the system is reliable enough to be used for the automation implementation in aquaculture systems with limited economic resources, to improve the profitability and contribute in the aquaculture sustainability problem. The TAN concentration into the tank is in function of the food amount supplied to the fish and the food amount is given according to the water temperature conditions, so, in each feeding time the food ration is changed. With this implication, it can be determined that the TAN concentration is changed in each feeding time, presenting a raising behaviour. The principal task of the FDACD is to control the TAN concentration, in function of a previous

Table I. Parameters input to the FDACD-TUNA™ system

Parameters input	Units
Volume	20000 (L)
Biomass	40 (kg)
Daily feed rate	5 (%)
Protein content in food	45 (%)
CH concentration	0,1 (kg L^{-1})
Dosage per day	6
Start feeding	8 (h)
Stop feeding	18 (h)
Flux feeder	120 (g min^{-1})
Flux pump	10 (l min^{-1})

Table II. Feeding criterion input for the FDACD-TUNA™ system

Feeding criterion input			
	Temperature		Dosage factor
t1	20	f1	0
t2	22	f2	0,5
t3	24	f3	0,6
t4	26	f4	0,8
t5	28	f5	0,9
t6	30	f6	1

Fig. 1. System schematic diagram: (A) fish tank with temperature and pH sensors; (B) water and sugar solution tank (CH) to send to the fish tank through a pump; (C) automatic feeder to fish feeding; (D) interfaz power to handle the pump and feeder motors; (E) dosage control (FDACD) with modifiable parameters by the user, through first program screen, displayed by the FDACD-TUNA™ system

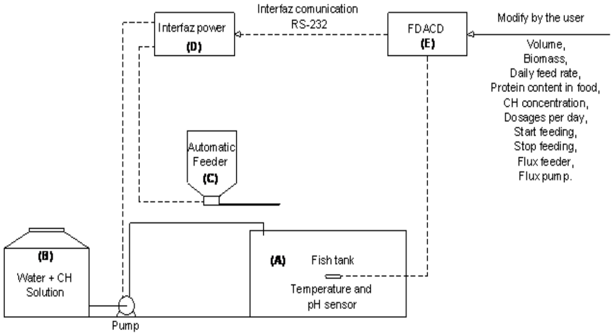
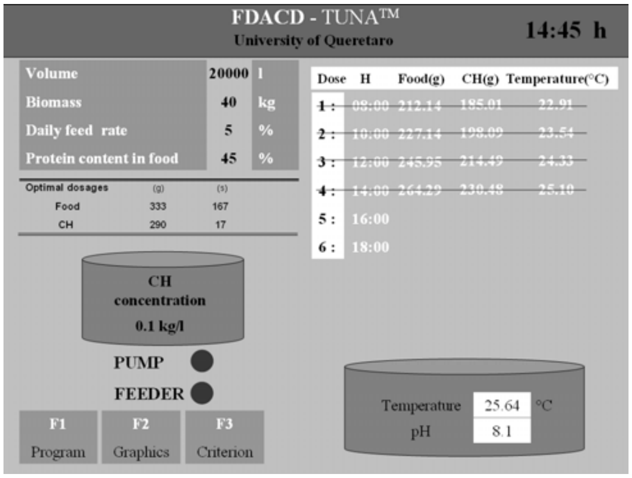


Fig. 2. Main FDACD-TUNA™ screen, which contains the general system information



FDACD - TUNA™
University of Queretaro
14:45 h

Volume	20000	l
Biomass	40	kg
Daily feed rate	5	%
Protein content in food	45	%

Optimal dosages	(g)	(s)
Food	333	167
CH	290	17

Dose	H	Food(g)	CH(g)	Temperature(°C)
~~1 :~~	~~08:00~~	~~212.14~~	~~185.01~~	~~22.91~~
~~2 :~~	~~10:00~~	~~227.14~~	~~198.09~~	~~23.54~~
~~3 :~~	~~12:00~~	~~245.95~~	~~214.49~~	~~24.33~~
~~4 :~~	~~14:00~~	~~264.29~~	~~230.48~~	~~25.10~~
5 :	16:00			
6 :	18:00			

CH concentration 0.1 kg/l

Temperature 25.64 °C
pH 8.1

Fig. 3. Water temperature behaviour during the experiment

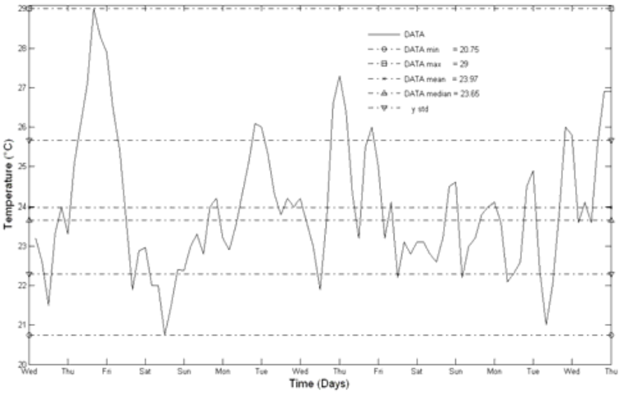


Fig. 4. pH behaviour during the experiment

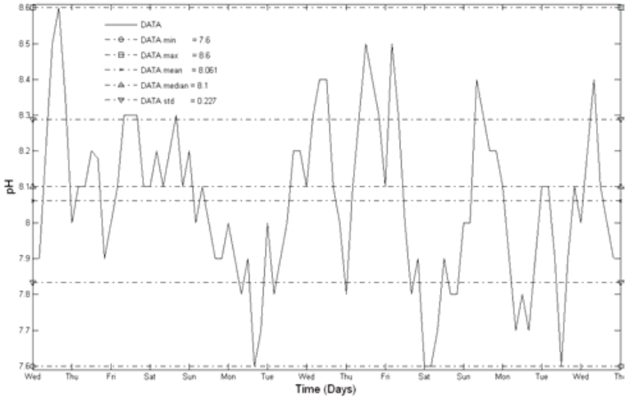


Fig. 5. Historical food dosage during the experiment

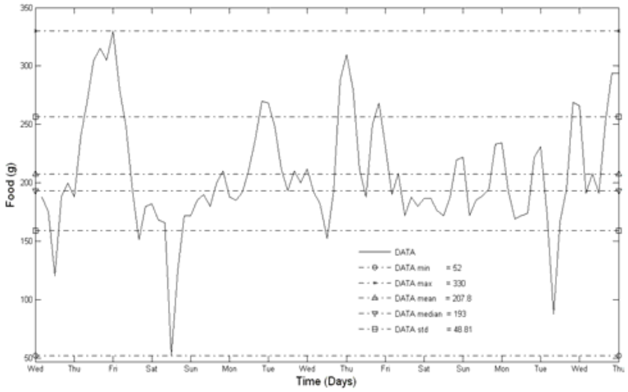
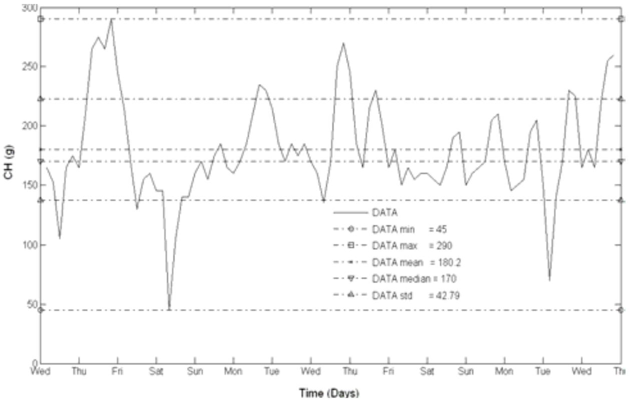


Fig. 6. Historical CH dosage during the experiment

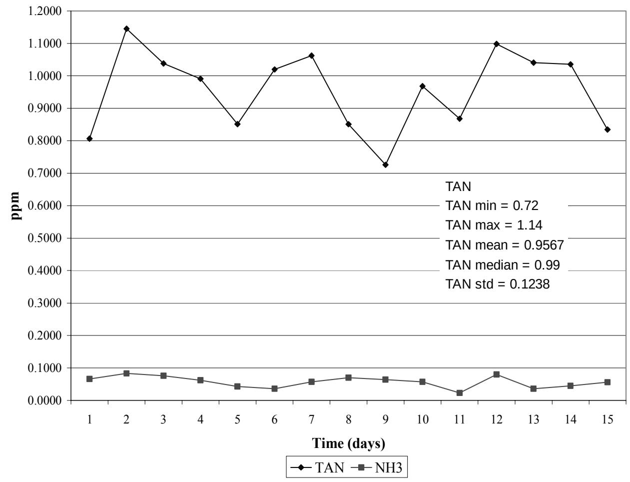


recorded and measured data (temperature & pH), in order to neutralize the accumulation of the toxic effect via the Avnimelech (1999) method, by using CH addition. Notice that the TAN is the main parameter in the nitrogen accumulation in this approach, since heterotrophic bacteria are the most common mean to eliminate it, therefore nitrites and nitrates were considered insignificant in this process. TAN and NH_3 behaviour are presented in Fig. 7; the TAN concentration was generated through the NH_3, water temperature and pH. In this experiment the TAN oscillatory behaviour was between 0.72 and 1.14 ppm, the NH_3 was between 0.023 and 0.083, demonstrating that CH addition reduces the TAN accumulation in aquaculture systems and can be easily controlled by the FDACD developed in this work, considering that the TAN acceptable concentration in fish production is TAN < 1 (Avnimelech, 1999) and the results showed a behaviour into this acceptable range. So, with the use of FDACD, aquaculture systems can obtain great benefits by using low cost devices in order to increase the profitability of this important production area.

DISCUSSION

The CH addition effect was tested on the immobilization of TAN, demonstrated by Avnimelech (1999). The experiment and its replicates did not show significant differences (P>0.05) and the survival rate was 100% in all cases. Fig. 3 shows the water temperature behaviour in the tank, meaning the fish feeding must be adjusted, because fish metabolism depends on water temperature. Eq. (5) was developed according to the management in this fish farm and considering the performed

Fig. 7. TAN and NH_3 behaviour during the experiment



studies that demonstrated the temperature effect in weight gain and feed intake in poikilothermic fish species, but it is suitable to be modified according to the needs of the user.

The CH supply is proportional to the food amount, given that, in Eq. (1) the only variable is the food dosage. On the other hand, TAN regulation via C/N ratio manipulation showed its efficiency in Fig. 7, otherwise, the TAN will be increasing each day. During the experiment, no water was replaced; though, removing the excess in the sediment will be necessary in the case of lager experiments.

By using this approach approximately 37% of food was saved, obtaining almost the same production achieving a FCR = 1.8 and reducing unnecessary water waste caused by the 37% of food that was consumed by fish in this experiment. This 37% was saved by the food amount variations established by the feed criterion input. The TAN (toxic component, NH_3) was maintained below the levels considered detrimental to fish (Grommen *et al.*, 2000), presumably by the CH addition; and the system maintained "zero discharge" during the experimental time.

The FDACD allows measuring and calculating the food and CH dosages for each feeding time. Performing this activity in a manual way is very laborious and increases the production costs, since without the system, it is necessary to hire a person almost exclusively dedicated to calculate the feeding dosages. The experiment was done in four tanks, but this control system can be expand up to fifty modules, to control four tanks, depending on the farm dimensions and tanks quantity.

CONCLUSION

Since feed material is the major expense in aquaculture operation, food dosage according to the water temperature approach is considered to be an effective method to obtain an important reduction on food and water waste. Fish are poikilothermic vertebrates and water temperature influences their feed intake; besides, water waste represents high costs for water treatments and a big problem in places, where water is not easily available. Obviously, the savings obtained by using this approach depend on the weather conditions and they are more evident when the water temperature can be artificially controlled; unfortunately, feeders that work only by timer do not have this advantage.

On the other hand, the method proposed by Avnimelech (1999) to reduce feed cost and water input is considered to be very effective in despite of the need of adding CH, which represents an additional cost. In this particular experiment, sugar was used to fulfil this requirement, being the sugar cost almost equal to the fish food one; even though, it is possible to use a cheaper CH source. Nevertheless, it must be considered that all nutrients are recycled, reducing costs since the protein content in the food could be reduced.

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