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Full Length Research Paper

An Automatic Feeder with Two Different Control Systems for Intensive Mirror Carp Production

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Feeding management provides the producer with an efficient tool to overcome limited feeding that may exhibit aggressive behavior during feeding due to limited feed availability resulting in carps that do not reach maximal growth. Overfeeding results in uneaten feed, poorer water quality, lower economic profit and additional environmental pollution. An automatic feeder was constructed and evaluated to provide predetermined amounts of food to four 9.5m diameter tanks stocked with 7000 organisms. Three tanks worked as rearing tanks and the fourth as nursing tank. Growth methodology optimized carp production in tanks which are grouped in four. These big tanks require of a better food distribution so three points of the tank were selected: two aside the edge of tank wall and another close to the center. Each point or wireless controlled gate provided the necessary food giving more chance to the fishes to obtain their provisions without competition. The system uses a hopper capable of feeding the four tanks during a week and its precision was dependant on a weighting mechanism. Two ways were used to control food provisions in this work. An opened control system based on the ATM89c51 microcontroller controlled the exact dosing based on the tank requirements according to the carp cycle and the other closed loop control system was determined by the conditions of water temperature, fish age, body weight and the amount of oxygen consumed. The amount of oxygen consumed by carps was the best parameter knowing fish metabolism and growth that the feeder can rely on it controlling meals provisions. The results show minimal differences in growth (P<0.05) between treatments, important food saving of 25.337% (equivalent to 3495.5kg), and lower water pollution (reduced water dissolved solids and ammonium components) compared with the first automatic feeder.

Keywords*:* carp feeder, weighting mechanism, opened and closed loop control systems, oxygen consumption, and intensive aquaculture systems.

INTRODUCTION

Aquaculture systems represent an important food production system with high-quality protein for human consumption. Increasing productivity and optimizing energy use are two fundamental aspects for successful aquaculture. Fish have a low feed conversion rate and in intensive aquaculture systems food represents approximately 40% of total production costs (Chang et al. 2005). Food excess causes unconsumed food deposits on the tank bottom and their decomposition will consume oxygen and produce ammonia-nitrogen (Chang et al. 2005). Competition behaviors are reduced if all fish are fed similarly throughout the tank, giving wide access to food (Jobling et al. 1995). In Mexico more than 50% of the fish ponds are located in remote areas as hills and electricity is not available. Maximum fish growth cannot be achieved using classic methods of feed administration by personnel due to human and logistic limitations as lack of night-shift workers. Different time-automatic feeder designs are available as belt feeders that work on wind-up springs, and electric vibrating feeders that can be programmed to feed hourly for extended periods (Saravanan and Santhanam, 2008). Other automatic feeders have been reported for feeding within predetermined time schedules for a certain feeding rate, without food outlet weighting process (Juell et al., 1993, Fast et al., 1997, Fang and Chang, 1999, Fang et al., 2002 and

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Yeoh et al., 2010).

Timer-controlled automatic feeders with a rotating plate and scrubber are widely used in indoor re-circulating eel culturing (Chang et al., 2005). Pneumatic feeding systems have gained acceptance in commercial fish farming due to its flexibility, simplicity and environmental compatibility (Chapelle et al., 2004). Demand self feeders depend upon the ability of fish to press a lever for getting food and can be manually or electronically controlled. Manual self-feeders are simple and cheap, but the gate mechanism often gets jammed; feeding can easily be induced by accident by fish swimming through the gate or by wave action (Shepherd and Bromage, 1989). Food portions are difficult to adjust, and it is not possible to spread food over the water surface (Alanärä, 1996). An electronically controlled self-feeding system consists of a trigger rubber knob, a control unit and a feeder. As the fish stretches the knob to eat it, pressure changes are monitored by the microphone which sends a signal to the control unit. However, the majority of the fish do not trigger the mechanism and food delivery is lost (Alanärä, 1992). Chang et al., (2005) used an infrared photoelectric sensor for starting and stopping feeding depending on the gathering behavior under the feeder; this method do not work properly with distributed food or with intensive fish tanks. Papandroulakis et al., (2002) implemented an automated feeding system for larvae computing the plankton organisms required according to feeding tables; a programmable logic controller (PLC) activated a peristaltic pump and solenoid valves for food distribution to the tanks. Foster et al. (1995) utilized a submersible camera to count the output of pellets using image analysis tools to determine the food quantity provided. Buentello et al. (2000), Cnaani et al. (2000), Avnimelech (2005), and Xu et al. (2006), stated that water temperature and dissolve oxygen affect feed conversion rate, since they affect fish physiology functions reflected in fish growth.

Many machines have been constructed thinking in photovoltaic powering as photovoltaic panels can provide excellent energy on places with daily radiation of 4-6kWh/m². (Fullerton et al., 2004) designed a feeding mechanism which uses a small electrical powered pump to actively force feed slurry down to a cage. A wind generator and solar panels provide power to the various pumps monitoring also the operation of the electric power system. Solar panels work efficiently charging batteries sized to provide 2.5 days of reserve capacity to 50% depth of discharge (DOD). The present work describes the operation of a PV solar driven automatic feeder with two different control systems for three commercial tanks growing 7000 carps each and another nursing tank. An opened loop control system was operated according to feeding timetables, and the other type of control (closed loop system) has some difficulties to apply because there is no sensor can measure animal appetite and the amount food require at each moment. For closed loop control system designing, the oxygen consumption sensing was used in place of appetite sensing. A minimum energy consuming feeding system was developed using all the technology available including wireless transmission, solar energy and precise dosing. Three feeding gates per tank were used to reduce fish competition for food. An image analysis studied transport phenomena during food distribution to understand system limitations.

MATERIALS AND METHODS

Two treatments with three replications were adopted in the experiment. In first treatment, feeding was performed with the feeder developed by (Elmessery, 2011) the corresponding fixed feeding time considering fish age and body mass. The feeder control executes an opened loop control. Three and six food sessions were applied per tank at the rearing and nursing tank, respectively through its three gates which allowed better food dispersion The three feeding sessions were at 9:00, 14:00 and 19:00h meanwhile the six sessions were applied at 7:00, 10:00, 13:00, 16:00, 19:00 and 22:00h. The food feeder was installed in the center of the fish growing area and distributed to each nursing or rearing tank's gate according to Tables 1 and 2. In treatment 2, the feeder was controlled by Lab View 2009 to introduce the food sessions at times of higher oxygen consumptions. Oxygen consumption by carps was studied under water temperatures ranging between 17 and 24°C for different carp sizes. Oxygen consumption was used as a determinant for feeding requirements by calculating active fish biomass based on oxygen consumption, so the feeder controller executed under a closed loop control. The comparison between the two ways of control was studied according to cap conversion factor and food saving

Feeder operation

Four sections are encountered at the automatic feeder (Figure 2a):

1. Food hopper
2. Feeding management control
3. Weighting mechanism
4. Food delivery to tanks.

The one and half cubic food hopper was designed for feeding the fishes during one week; a capacitive proximity sensor detected food absence setting an alarm. The food delivered per week under the first type of control was of 495.6kg during the first month (Table 1 and Table 2), and increased to a maximum of 772.8kg on the last month when the four (rearing) tanks fed carps five month old, Table 1.

Table 1: Monthly feeding for each tank containing 7000 organisms with three meals daily.

Time	Daily feeding mass per tank (g)	Meal mass (g)	Feeding (g) Every doses per tank		
			1st gate	2nd gate	3rd gate
Third Month	18000	6000	2000	2000	2000
Fourth Month	18000	6000	2000	2000	2000
Fifth Month	27600	9200	3200	3200	3200

Table 2: Monthly feeding for the nursing tank with six meals daily.

Fish numbers in the tank	Time	Daily feeding mass per tank (g)	Meal mass (g)	Daily feeding mass per tank (g)	Feeding (g) Every doses per tank		
					1st gate	2nd gate	3rd gate
21,000	First Month	16800	2800	16800	900	1000	900
	Second month	25200	4200	25200	1400	1400	1400
28,000	First Month	22800	3800	22800	1200	1400	1200
	Second month	33600	5600	33600	1800	2000	1800

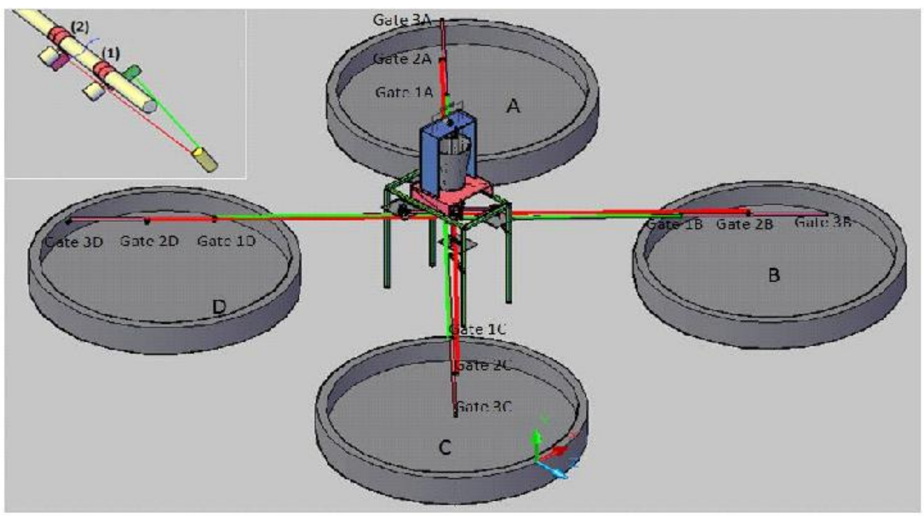

Figure1: Anautomatic feeder and carp tanks.

The feeder controls the food delivered to t h e tanks by moving one motorized plate; when the holes (Figure 2 b) of the two plates coincide the food passes to the weighting mechanism. The bottom plate turns around while the fixed top plate avoids excessive load to the motorized plate. The bottom plate is turned by a 17.8W direct current motor supplied by 24V DC (mod. AST-G002DC, Geared Motor, USA). The m o t o r rated torque was of 34J and rotated at 5rpm.

Two positions are required for feeding the four tanks: the sync position and the rearing position. The feeder motor turns the bottom plate until the first opening synchronizes with the top plate hole acknowledged by micro switch one; the internal rod within the weighting mechanism for nursing or rearing tank A is filled with food. Once the weighting setup is reached a micro switch gets activated and the feeder motor turns fishing rod filling with food. Synchronous food control for the other three rearing tanks required of three holes displaced 90°, 180° and 270° from the sync position. The moving plate has to be rotated 90° to fill the rods with food f o r the rearing tanks. The weighting micro switch gets activated finishing rearing tanks dosing. The sync orifice has to be acknowledged again by turning the bottom plate by 270° so it is ready to dose tank A again. The weighting mechanism presented two overlapping PVC tubes and its sequence is shown in Figure 3, being the internal rod filled with 100g in 15 seconds. The food dosed to each tank will be proportional to multiples of 100g .The internal 30 cm long PVC tube presented a fixed lever where a 2.5cm long spring (A) of 0.1N /mm w a s connected. The other side of the spring is fixed to the external PVC rod. As the rod fills up, the lever moves down through the external rod slot until the weight micro switch (WMS) is

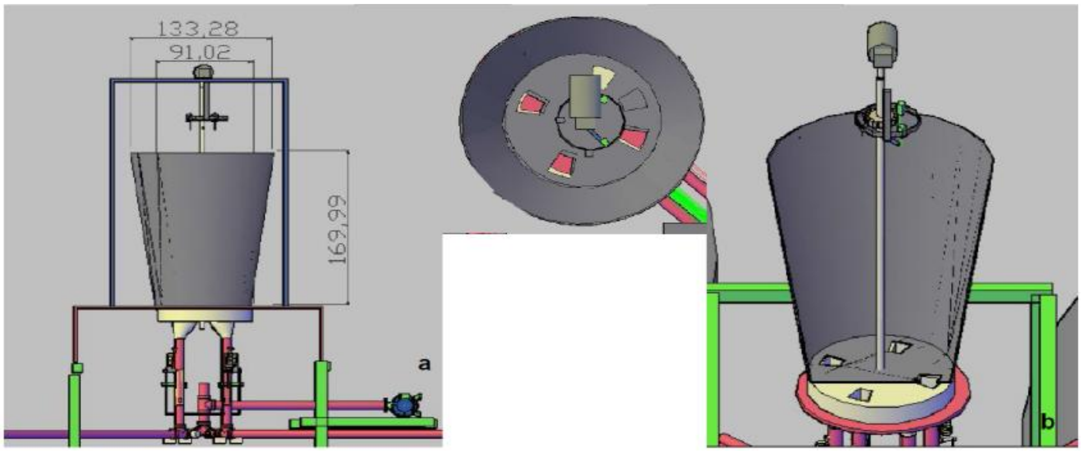

Figure 2: Automatic feeder showing its (a) lateral view; and (b) internal shaft system (c) two perpendicular views top and bottom.

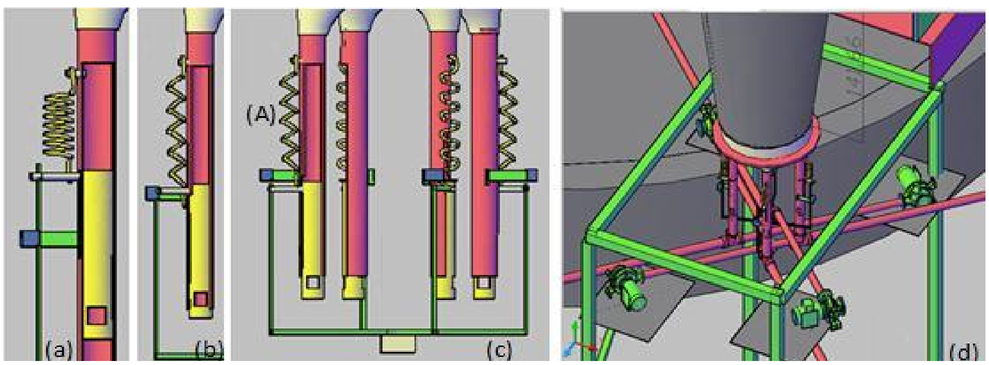

Figure 3: Weighting mechanism show a) initial position, b) after one hundred grams, c) electromagnetic coil firing and d) fan configuration.

activated, Figure. 3b; Food entering the rod is restricted when the motor turns clockwise 10° arriving to the stopping position. If the same rod has to be refilled the motor is rotated counter clockwise 10°C. The WMS signal is received by microcontrol port 1.3 and two seconds later two 4W at 24 D C electromagnetic coils (mod MAGMAX, ALCO, USA) were fired attracting a ferric rod fixed to the internal rod. One coil was fixed at the center point beneath the three tubes feeding the rearing tanks and the other one pulled only the rod that fed the nursing tank A. The coil avoids that the internal PVC rod returns to its initial position until it is completely empty, Figure 3c. At this moment, 24V DC air extractors (model KZFF 263, Guangzhou Keao Electrical Co., Ltd, China) were turned-on.

One fan activated by P 10 fed nursing tank A, Figure 3d. T h e P1.4 signal turned-on the other three fans which fed simultaneously the rearing tanks. Three output gates deliver the food to each tank situated at the PVC tube standing over each tank, Figure 1; two automated gates controlled the opening and closing of outlets 1 and 2. A thin circular plate rotated inside the gate was derived by a 4.22W at 12V DC gear motor (model EMG30, Technobots Ltd. UK) and supplied by a 12 - Volt rechargeable battery (model LC- R121R3P, Panasonic, USA). Gates stayed normally opened allowing food application to gate 3. Four green and four red lasers were fixed at the bottom tubes of the hopper establishing the wireless communication between the control and the gate motor drivers (Figure. 1 and 2a). Laser signals activated by P1.5 and P1.6 close the valves; red laser closes gate 1 meanwhile green laser closes gate 2. Photo detectors waiting for the laser light are fixed at opposite sides of the distribution tube at the gates and when laser light is detected the gate closes for 12seconds.

Opened loop feeder control

At this type the automated feeder was controlled by an embedded system based on the ATM8 9 C5 1 (ATMEL Inc, San Jose, California) microcontroller. The microcontroller port configuration is depicted in Table 3, and a LUT (look up Table) stores the information for food

Table 3: Port configuration.

	Port Configuration							
Port 1 Name	P1.0 NTF	P1.1 MI	P1.2 MS	P1.3 WMS	P1.4 RTF	P1.5 Laser control	P1.6 Laser control	P1.7
Defin	0-Nurse fan cont 1-coil turn off	Motor Feeder 0-cw 1-ccw	Micro Switch	Weight Micro Switch	0-Rear fan cont 1-coil turn off	Green aser	Red laser	
Port 2 Name Defin	P2.0 T1 0-finish 1-1st month 21,000	P2.1 T1 0-finish 1-1st month 21,000	P2.2 T2 0-finish 1-1st month 28,000	P2.3 T2 0-finish 1-2nd month 28,000	P2.4 T3 0-3rd month 1-4th month 7,000	P2.5 T3 0-5th month 7,000 1-aut.	P2.6 T4 0-3rd month 1-4th month 7,000	P2.7 T4 0-5th month 7,000 1-aut.

dosing per gate during the different months for both rearing and nursing tanks (Tables 1 and 2). Port 1 considers fan control, laser turn on (P1.5 and P1.6) and motor control. Manual instructions of the operational status of the tanks are provided by external switches in Port 2. If all the fishes have the same growth the system can run with an automatic routine by setting P2.7 to one. Manual operation of T1 and T2 (P2.0, P2.1, P2.2 and P2.3) will indicate whether the feeder feds nursing tank A with 21,000 or 28,000 fingerlings. If tank A is converted to a rearing tank and fed 7000 juveniles P2.4 and P2.5 are accessed. Manual control of T4 is used to feed rearing tanks B, C or D whether they are three, four or five month old fishes. Under situations when no fishes are encountered in o ne of the three tanks B, C and D, the specific fan must be disconnected and the hole at the corresponding rod closed.Once configuring monthly microcontroller Port 2 the appropriate feeding signals are sent to the feeder using Port 1.

Closed loop feeder control

Oxygen consumption in the tank was measured using only one sensor (galvanic probe (HI 76410/4, Hanna Instruments, USA)) was connected to a panel mounted controller (mod. HI 8410, Hanna Instruments, USA) with two 24W at 0.356liter/min peristaltic pumps (mod 41k25GN-AUL-ES, Oriental Motor Co. LTD, Japan) were installed at the inlet and outlet fish tank. The controller 4-20mA recording output was connected to a USB acquisition with personal computer programmed by Lab View. The relationship between specific oxygen consumption (gO2/kg [BM].h), water temperature and mean fish mass was studied. Control simulations were carried out using the Tool Box of the commercial software MATLAB R2009b. The food was delivered six times during the day.

The control algorithm was as follow.

1. Carp age.

The carp age can be obtained manually by user or automatically by the program timer.

2. Carp mean mass.

The carp mean mass can be determined mathematically by Equation 1 from Elmessery, 2011(under optimum growth conditions) or manually entered by user.

$$CMW = 18.239 \times e^{0.01837T} \quad 1$$

Where CMW is Carp mean mass (g) and T is

Carp age (days)

3. Acquire water temperature by Thermopare type K.

4. Calculate Specific oxygen consumption gO2/kgh corresponding carp mean mass and water temperature using the simulated model of carp specific oxygen consumption calculated by Elmessery, 2011 (Figure4).

5. Acquire total oxygen consumption measured from the tank

6. Active biomas can be calculated by the following relationship:

$$ACB = TOC/SOC \quad 2$$

Where ACB is active carp biomass in the tank, the active fish biomass is defined as the amount of carp biomass that indeed has biological activities (searching food, swimming and etc.) All the environmental parameters (water temperature, dissolved oxygen, Total ammonia nitrogen and etc.) affect active fish biomass. It found that water temperature affect proportionally fish oxygen consumption and thereby active fish biomass, it doesn't mean when active fish biomass is for example 2000kg that the total fish weight in the tank is same, may be 3000kg but water temperature is lower than 27ºC, TOC is total oxygen consumption measured gO2/h and SOC is the specific oxygen consumption (calculated) based on carp mean mass and water temperature (gO2/kg [BM] h). Food requirements can be calculated based on active carp biomass and individual mean mass for carps by

Equation 3.

$$FR = 0.1959 \times CMW^{-0.437} \times ACB \qquad 3$$

Active carp biomass can be calculated by total oxygen consumption by the following equation:

$$ACB = 637.17 \times e^{0.01TOC} \qquad 4$$

Feeder performance evaluation and modeling

The feeder was evaluated for an entire season using SAS statistical analysis. Nutripec 4418C and Nutripec 3508 commercial fish food are recommended for nursing and rearing tanks, respectively and were dosed to the tanks by the automatic feeder. Nutripec 4418C is a floating food formed by particles having 1.7mm diameter and consists of 44% protein and 18% fat and its apparent density of 540 kg /m3. Nutripec 3508 presents 3.5 mm diameter floating pellets with 35% protein and 8% fat and its apparent density of 415kg/m^3. The following tests were carried out during the evaluation:

1. Diameter determination of the gate tubes and of the filling rod of the weighting mechanism.
2. Accuracy and losses of dosed food a t every gate and effect of air velocity on dosing precision.
3. Energy consumption analysis, including a wider weighting tube.
4. Laser calibration for wireless control of gates.
5. Air-food particles movement analysis.
6. Effect of air velocity on heat dynamics and its effect on feed temperature.

Pipe airflow was analyzed searching the optimum feeding at the lowest energy consumption. Images taken at the transportation tube were useful to observe the air turbulence in order to evaluate and model food transportt. Flat pieces were installed at the top of the tube to create turbulence for analyzing and optimizing feeder performance. Air Reynolds number (Re) effect on food transporting (laminar or turbulent), and its subsequent impact on the total fans energy consumption was analyzed. Two fans were coupled to a Y- PVC connector introducing different air velocities to the distribution tubes. Air Reynolds number (Re) was calculated by Eqn. 5.

$$Re = \rho VD/\mu \qquad 5$$

Where ρ is air density, V the mean air velocity (m/s), D the pipe hydraulic diameter (m) and µ the air dynamic viscosity (Pass). Two perpendicular 12 Megapixel cameras (mod. Easy Share M 5 3 0 , Kodak, USA) were installed over three 0.5m long a crylic tube sections placed at the three gates position. The cameras were set to take two simultaneously videos in orthogonal directions. The videos were converted to digital photos every 0.1second by the RealPlayer software and analyzed by the Image software to calculate the percentage of occupied space was calculated over the pipe cross section and occupied space volume. Temperature data was acquired from three thermocouples positioned at the gate positions on the distributing tube with an acquisition board (mod DAQ NI-USB 6008, National Instruments, USA). An infrared temperature probe (mod. 80T-IR, FLUKE, Germany) measured the acrylic tube superficial temperature.

Photovoltaic system and energy optimization

Solar panels produce energy under sunshine hours ranging from 5 to 6hours per day in the coastal area. The feeder photovoltaic system (PV) requires a battery for storing energy and a regulator between the panel and the battery; an inverter is not required as o n l y DC voltage is used by the motors , solenoids a n d controls. Battery a n d solar panel sizing was selected considering the days having the highest energy consumption which occurred in July (232.796Wh/day). If three days of autonomy are desired due to cloudy days, and supposing that the 24V battery bank only discharges 30%, the battery should manage 50 Ah. A 24 V at 50 Ah rechargeable LiFe PO4 batteries (Model L F 2 4 5 0, Optimum Battery Co., Ltd, USA) was used together with a current battery charger. The determination of the photovoltaic cells (PV) depends on the energy used per d a y and the 6hours of irradiance over 1000Wm2/day which is 2.3Ah; tw o 40W solar panels (mod. STA040-12, Suntech, China) were connected in series. The battery charger used a semiconductor switching element between the array and battery which switched on/off at a variable duty cycle to maintain the battery at or very close to the voltage regulation set point. Energy management per fan, solenoid and weighing mechanism was studied to optimize solar panel requirements.

RESULTS AND DISCUSSION

Fish consumes food in 5 to 10minutes in pond culture, but using timers can easily lead to overfeeding (Masser et al., 1999). Feeding rates measured as a percent of the average body weight vary with fish size and water temperature. As the mass of fish increases, the percentage for body mass fed decreases. Fish fed in 2–3hours intervals eat more feed than their stomachs can hold and is wasted; resulting is an increased cost of production and lower profits. Overfeeding wastes, degrades water quality, and can overload the bio filter. Fish fed at 4–5hours interval eat nearly the same amount of feed needed to refill their stomachs, being the optimal interval, depending on the energy and composition of the diet (Riche and Garling, 2003). This interval is the same that was used in the carp rearing tanks of this experiment. Ultrasound for monitoring uneaten pellets has been shown to be a useful means of reducing wastage (Summerfelt et al., 1995). When pellets are detected in the tank effluent, the devices discontinue feeding with an increase in growth of fish up to 60% compared with ration feeding.

Closed loop control system

Has been inferred from the primarily results that the food should provide to fishes in times of higher oxygen consumption during day, namely times of activity, searching for food, the feeder was programmed for introducing food in times from 10:30am to 9:30pm. According data collected of carp oxygen consumption and water temperature the program can determine fish biomass, thus the amount of food delivered based on fish biomass and age was simulated by MATLAB.

The food delivered increases as oxygen consumption and water temperature rising from 17 to 25ºC; these results agree with those obtained by Buentello et al. (2000) and Soto- Zarazu´a et al., 2010. It can be observed that the closed loop control has strict control over the temperature and carp oxygen consumption variables and their interaction in order to provide the precise food quantity. This ensures that the provided food quantity will be completely ingested by fish, thus food saving is obtained and water pollution rates also decrease.

Temperature, oxygen consumption, and food provision

Temperature and oxygen consumption measurements, as well as the food provided during the experimental period are shown in Figure 5 and 6. In these Figures, each point represents the temperature and oxygen consumption values and their corresponding food provided determined by the closed loop control in each feeding time. The water temperature measurements ranged between 17ºC and 25ºC, and the same trend were found in all tanks for both treatments. Fish regulatory mechanisms underlying relationship between growth rate and temperature are likely related to enzymatic modulation of metabolic process in fish (Sumpter 1992; Al-Asgah and Ali 1997). When temperature is high, the metabolic process increases, therefore a high food demand is present; on the other hand, when the temperature is low, food demand decreases too (Buentello et al. 2000; Valente et al. 2001).

Feeder performance

The effect of tube diameter for food distribution depends on the amount of air delivered from the fan. As the tube diameter decreased the outlet air velocity increased, so for 1” and 2” diameter tubes outlet air velocities of 19.1 and 10.8m/s were monitored, respectively. An air velocity of 14m/s inside a 2” tube diameter delivered 100grams of food at each gate in 12seconds. The food delivered in 4 and 8seconds at gate 2 with 2” PVC tubes was of 61.3 and 83.2grams, respectively. Less food was delivered at gate 3 during the same periods. The 2” diameter PVC tube weighting rod provided the better precision for both foodstuff. A 3” diameter PVC tube was not precise as the lever moved less producing 5.8 and 4.3% dosing errors for Nutripec 3508 and 4418C, respectively. Dusty food tends to fill better the rod volume than pellets where air spaces are formed. A 1” PVC rod was longer and the slot of the external PVC rod was difficult to implement. One hundred grams of dosed Nutripec 4418C produced food outlet at gate 1 ranging between 99.545±3.241grams. Weighted Nutripec 4418C output at gates 2 and 3 measured 99.394±3.239 and 99.33±3.4248grams, respectively. In a Bayesian distribution, 95% of the dosing occurred between 99.1 and 100.5grams. Nutripec 3508 food outlets from gates 1, 2 and 3 weighted 97.35±5.5275, 96.56±5.606 and 96.298±5.68grams, respectively. It was observed that the weighting mechanism worked better with Nutripec 3508 having a $R2=0.9816$ as the particles diameter was smaller and moved smoother through the PVC rod. These small particles stayed at the gate throats and settled at the gate edges. Nutripec 4418C presented $R2=0.9614$, $R2=0.9572$, $R2=0.9456$ during dosage at gates 1, 2 and 3, respectively.

Laminar and turbulent food flow was evaluating using one and two fans. When airflow within the tube was turbulent (Re=27,551) and its pressure drop 10Pa, food movement was laminar, Figure 7. Food movement became turbulent at Re=36800 when air pressure drop increased to 19.6Pa with a higher pressure drop of 49Pa the Reynolds number increased to 55200. The higher Reynolds number was achieved using both fans, while the lower Re number was obtained when only one fan was used. Food discharge time decreased from 12 seconds to 4seconds as Reynolds number increased from 27,551 to 55,200. Energy consumption decreased by 68% as Reynold number varied from 27,551 to 55,200. Nutripec 3508 pellets arrived at the first gate 0.45 seconds after turning on both fans; meanwhile it took 2.4seconds using only one fan. Nutripec 4418C powder felt to the tanks 0.5second after starting both fans and 2.6 with one fan only. Total distribution of the food finished 5.5seconds with turbulence (both fans), and 12seconds when only one fan was employed; the time required to feed 100grams (cycle time) was 16seconds, similar to the time interval response for self-feeders defined as the period of no response to subsequent bite activities after the feeder activation. Self-feeders response times varied from 3seconds (Yamamoto et al., 2000; Shima et al., 2001) to 15seconds (Alanärä, 1992, 1996) and 1min (Gėlineau et al., 1998). However, these varied response intervals simply reflect either the time required for single activation of the feeder (Yamamoto et al., 2000; Shima et al., 2001) or intervals chosen in order to avoid fish activating the trigger during food release (Alanärä, 1992 and 1996). The time cycle and the amount of food required by the feeder will take different times to give the required food in different months of growth. Maximum 103grams weight was obtained due to food accumulated along the tube during the previous dosing.

The lowest dosage of 95.9grams only happened once at the third gate of tank A and three grams remained adhered in the gate circular plates. In March the feeder delivered 16.8kg of food daily to the nursing tank, taking for six applications periods of 59.5min and 98min per day for WM resolutions of 400grams and 100gram respectively. In May three rearing tanks were fed of 54kg simultaneously in 63.75min per day and 105min per day for the resolution of 400grams and 100grams respectively, introducing three meals daily, respectively. In May the nursing carps were transplanted to the rearing tanks, so nurse tank A remained empty. In June the nursing tank was cultivated with 28,000 organisms, so the automatic doser fed the nursing tank and the rearing tanks simultaneously each with its respective quantities of 22.8 and 54kg, respectively. The rearing tanks were harvested the 29 of July and the nursing tank fishes were distributed between the four tanks. In the last three months the nursing tank was used as rearing tank with the 7000 organisms, and 110.4kg were fed daily on October. Total feeding time for a 4m3 tank with a ranged from 41-49min for stocked eels whose size ranged from 45 to 250grams, Chang et al., (2005). Food particle suspension flow varies considerably as Reynolds number is affected by heat, as food particles can transfer or generate heat energy in the gas-solid pipe system, Fig. 5.a. Acrylic tubes substituted the gates and were maintained open, taking the measurements at 10:00AM when air temperature was of 19.5°C. Tubes surface temperatures measured with the infrared thermometer were 25.8, 26.5 and 24.8°C for the first, second and third acrylic tubes, respectively. Air temperature of food transported by one fan was higher at the second acrylic tube (second gate) than at the first and third acrylic tubes. Food particles transferred a heat of 0.41652 kJ from the first to the second gate as shown by the interval between the blue marks, Figure 8a. As the fan stopped (after the second mark) the temperature of the air inside the second tube decreased, with a similar but inverted slope so food temperature was higher than surface temperature, Fig. 8a. When two fans were used tube 3 air temperature started to increase over tube 2 temperature when food and air was transported, Fig. 8b; Air speed increased twice and the Reynolds shear stress was doubled. With both fans on a heat energy of 0.4137kJ was transported from the first to the second gate by the air and particles; with an added kinetic energy of 0.09825kJ the total heat gain was of 0.51195kJ, which explains the temperature increase at the third gate.

Gas-solid interactions due to various stochastic factors in the form of particle collisions, air turbulence and vortex contact between them are viewed in longitudinal and orthogonal images, Fig. 9. Particles fed in the tube with zero velocity accelerate horizontally by the drag force moving across the air stream until each particle falls at its own terminal settling velocity. Regulated air speed ensures optimal pellet flow, if it is too low the risk for pellet blockage is increased (Sorensen et al., 2008). If the pellet/air speed is too high, dust and breakage is increased. As turbulence increased with the use of both fans (Re= 55, 200) food occupied more than 80% of the tube area, Fig. 9e. A jet of air transporting the pellets was imaged along the acrylic tube and floating is noted, Figure 9b and Figure. 9d. with only one fan working pellets occupied only 30 % of the area and most of it carried dust, residuals and even pathogen that produce fish diseases, Figure. 9e. A top longitudinal image taken at the acrylic tube show that food is disperse Figure 9a, meanwhile a lateral image shows how pellets remain in the bottom of the tube due to poor air force, Fig. 9c. Air speed increased twice and the Reynolds shear stress doubled and the occupied space volume per linear meter increased. The pneumatic conveying system presented in this paper used positive pressure and a dilute phase mode characterized by large amounts of transport gas with no speed limits and little quantity of solids conveyed in the suspension (Klinzing, 2001). Air flow exerts thrust force on the cross section of pellets and the drag force accelerates them to move forward (Salman, 2002). Long small diameter pipelines with coarse wall increase intensity of collisions between feed and pipes generating dust and pellet fracture (Sommerfeld and Kussin, 2004). Food particles collisions were monitored by a sound detector (mod. DIGITAL SOUND METER, Radio Shack, USA). The highest collision grabbed with one fan was of 72db at the first gate, and decreased at the third gate were the sound intensity acquired was of 65db. Sound intensity of collisions caused by the operation of both fans reached 82db. Too high airspeed generates turbulent flow, depredates pellets and wears out the pipeline, but feeding rate can help to protect pellets (Aarseth, 2004). Pipe blockage can occur under very low conveying airspeed, which never occurred during the evaluation of the system. Operation with one fan was just over the minimum airspeed limit operating with low turbulence and being unable to lift the pellets in the air, Figure 9c.

Food passed through the tubes and from every pair of orthogonal images the percentage of space occupation was obtained. Food particles at tube 2 presented a higher cross section occupied space percentage than the first tube being the air-food mixture inside tube 2 hotter due to the heat energy increase, Fig. 10a; maximum occupied space percentage using one fan at gate 2 was 59.337% and 44.17% for Nutripec 4418C and Nutripec 3508, respectively. The cross section occupied space for gates

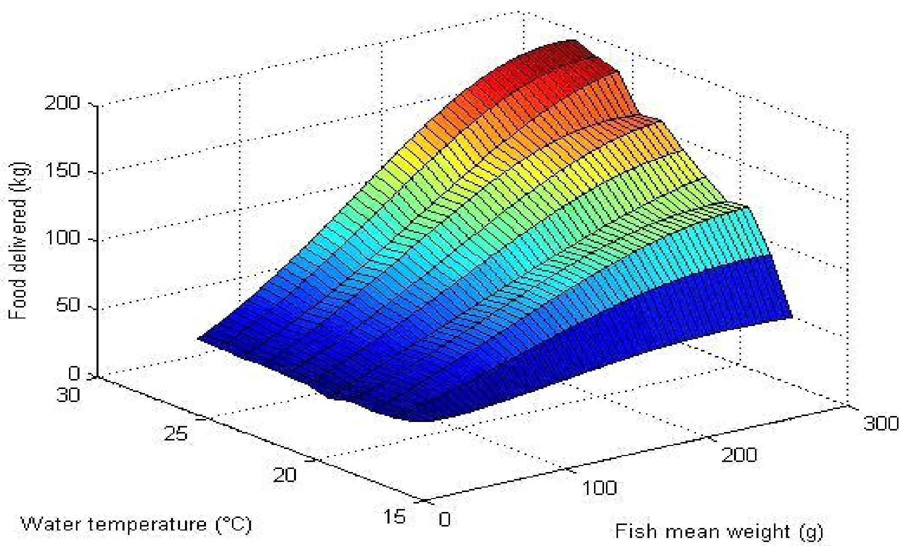

Figure5: Controller simulation results for t h e completeoperation range of temperature, fish m e a n s m a s s and food deliveredfor28,000carpsin the four tanks.

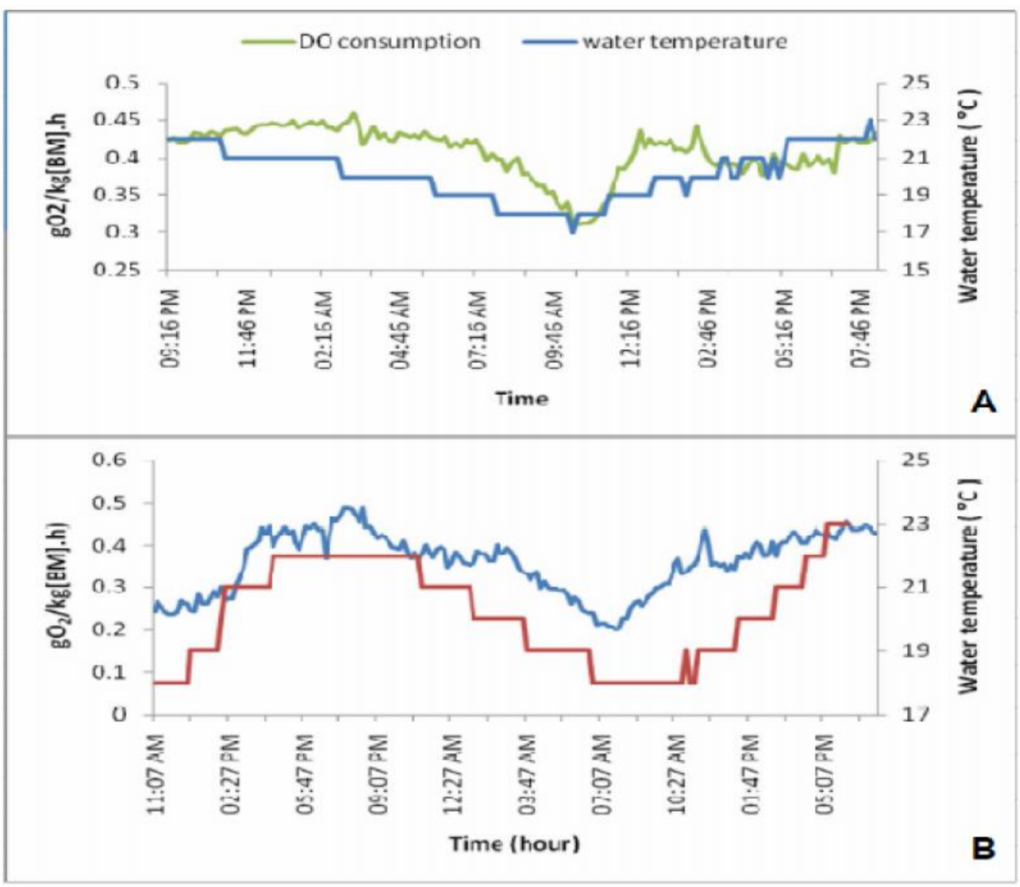

Figure 6 : Carp o x y g e n consumption (gO2/kg[BM] h)for mean w e i g h t 200grams (A) and 150grams (B) under different water temperatures during the day.

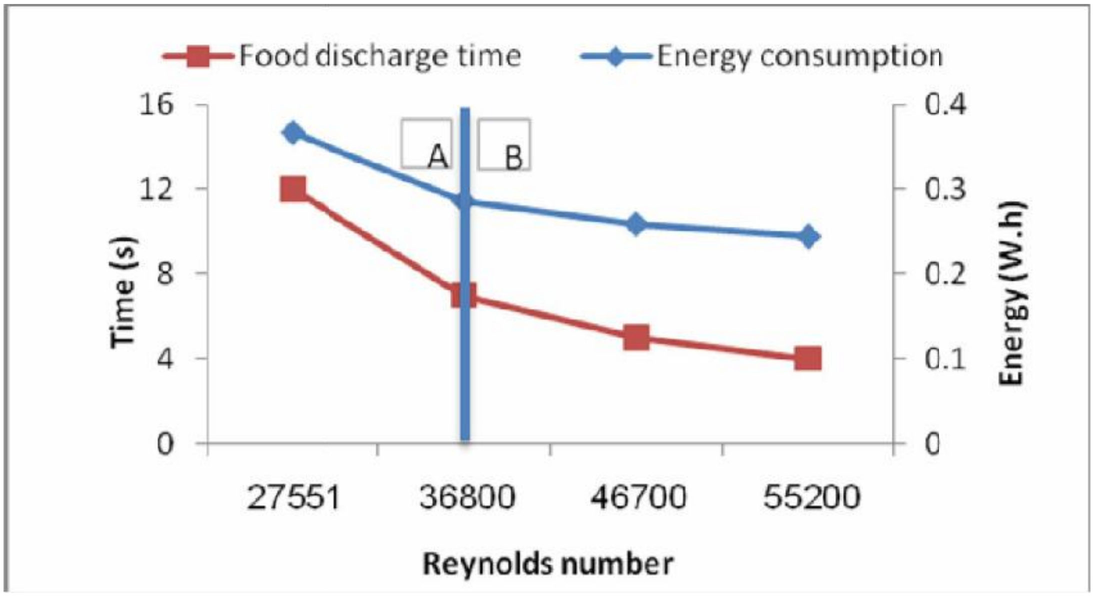

Figure 7: Air Reynolds number effect on fan operation time and energy consumption for laminar (A) and turbulent (B) Nutripec 3508 movement.

2 and 3 for Nutripec 3508 with one fan was of 44.17% and 40.086%, respectively. The highest occupied percentage was obtained at gates 2 and 3 with 86.29 and 91.93%, respectively when the two fans were operating, Figure 10b. This analysis implies a higher turbulence as food travelled through the 9m tube, creating different collusion regions until mass flux distribution becomes more distributed. For the lowest Reynolds number = 27551 used with one fan maximum particle mass flux occupied 42.4% of the pipe cross section; with two fans at Re = 55200 maximum particle mass flux occupied 91.93%. (Fouad et al., 2010) studied gas-solid flow in a horizontal pipe for two silica sand and aluminium oxide particles having densities of 2700kg/m3 and 3800kg/m3, respectively. For Re=5.4×104 particle local mass flux at the bottom of the pipe was 50 times greater than at the top; at Re= 1.91×105 particle mass flux at the bottom of the pipe is only 4 times greater than at the top. It was observed that food performed with a pulsed behavior during its movement throughout the tube. Different collision regions were created until mass flux distribution became more distributed over the cross section, Fig. 10b; non-uniformity decreases with solid particles redistribution within the pipe cross section. Turbulent diffusion and momentum transfer from the fluid to the particles tend to support more particles distribution. Food became hotter as the Reynold number increased and for Re=55,200 being of 1.5 and 2ºC for Nutripec 4418C powder and Nutripec 3508 pellets, respectively.

The fed particles enter with the air stream of the fans and when both are used a screw- type flow is created. Particles rotate while drifting radially reaching the pipe wall at different locations (Shapiro and Galperin, 2005). Larger particles arrive to the wall faster; smaller ones make it farther along the axial direction. During this interval the tube was hotter 7ºC hotter than air and acoustically the impacts presented db. When both fans operated tube 3 air temperatures was hotter than tube 2 temperature. Air speed increased as particles moved with turbulence increasing particles collusions at the second and third gates over the first gate which presented three decibels less. The diameter of 50cm and the diameter of the tank was 110cm for height of 80cm to fill all the area of the tank theoretically the tube must be positioned at height of 196cm. Air- solid particle flow turbulence varied greatly with particle size and 3.4mm of plastic particles increased turbulence with respect to 0-2mm ones (Tsuji and Morikawa, 1982). As well as feeding timing optimization, the location of feeding can affect both the quantity of solids wasted and their distribution within the culture facility. Two longitudinal slots in the tube between the second and third gates could be an option for better food distribution. Solids concentrations from culture vessels that have been increased in order to increase treatment efficiency, can be discharged either as a continuous stream of a lesser flow than the primary effluent, or as a discontinuous stream of short duration–high flow pulses.

Energy consumption and solar and photovoltaic system

Daily energy consumption to feed the fish tanks was used as a feeding efficiency index (dosed food kg/kWh), the feeder efficiency was measured for two designs of one fan used for distribution tubes with higher resolution of

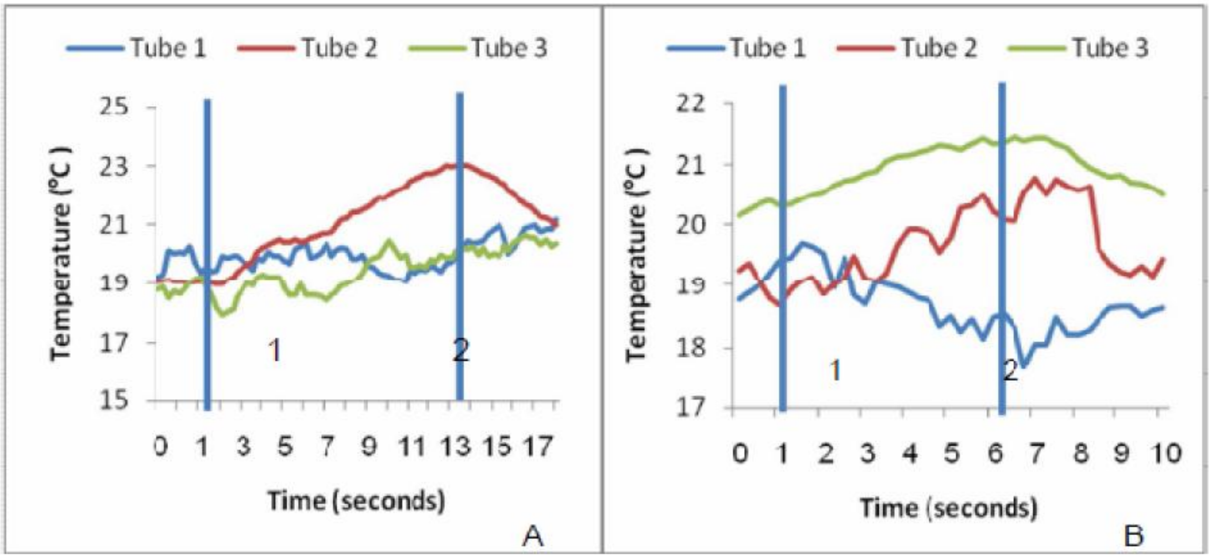

Figure 8: Air temperature measured at the three arcylic tube for (A) fish food Nutripec 3508 transportation by one fan and (B) by two fans

Figure9: Effectof usingone fan (A, C) andtwo fans(B, D) on particles movement and flux distribution, together with cross section images(E,F).

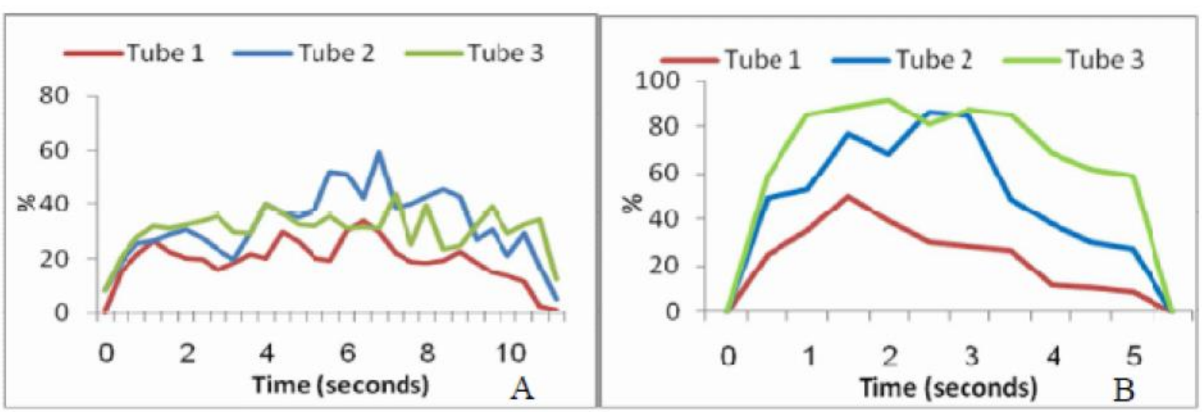

Figure 10: Food particle distribution along the pipe cross section given as percentage for Nutripec 4418C at each gate using (A) one and (B) two fans.

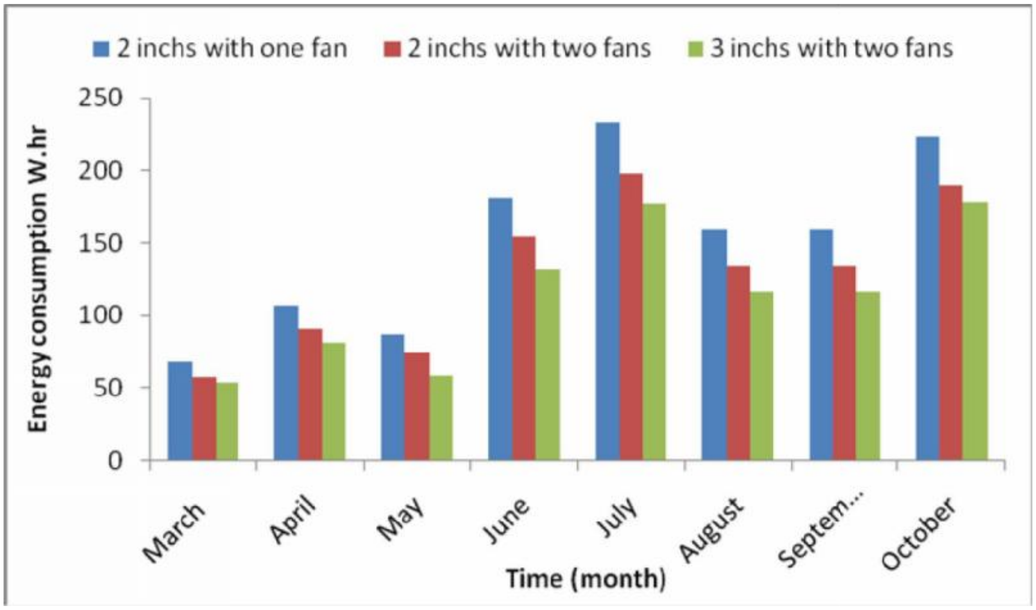

Figure 11: Daily energy consumption for different months for one fan with higher resolution (2inchs), two fans with higher resolution (2inchs) and two fans with lower resolution (3inchs).

Table4: Performance parameters of mass and in take a tthe beginning and end of the experiment for both treatments.

Parameter/treatment	**Openedloop control**				**Closedloop control**			
	Tank1	Tank2	Tank3	Tank4	Tank1	Tank2	Tank3	Tank4
Initialcarpmean mass,g	22±0.3	21±0.7	23±0.5	24±0.7	22±0.3	21±0.4	21±0.54	20±0.8
Finalcarpmean mass	198	197	199	198	250	240	260	240
Totalcarpbiomass produced,kg	1298.35	1310.0	1323.35	1316.7	1662.5	1596	1729	1596
Feedintake,kg	2778.5	2921.5	2699.63	2738.74	2693.25	2617.44	2697.24	2601.4
Feedconversionrate	2.14	2.23	2.04	2.08	1.62	1.64	1.56	1.63
Survival,%	100	100	100	100	100	100	100	100

weighting mechanism and two fans used with distribution tube with lower resolution of weighting mechanism the difference between the two resolutions did not affect statistically on food outlet precision. A high feeding efficiency index of 315kg food/kWh was obtained in May as the three rearing tanks were fed simultaneously. The feeding efficiency index decreased to 308kg food/kWh respectively in June when the nursing tank fed 28,000 juveniles during the second production cycle. As the food requirements increased in all the tanks in July the feeder efficiency increased to 315.42 kg food/kW.h.

When the juveniles were transplanted to the four tanks the feeding efficiency index decreased to 309.15kg food/kWh respectively in August and September. The feeding efficiency index is higher when it feeds different fish tanks saving a lot of energy, for this reason when the tank feed nursing tank only the feeding efficiency obtained was 293 kg food/kW.hr, on the other hand when the feeder feed the rearing tanks only 325.6kg food/kWh. Energy was consumed by the fan, coils, and hopper motor. Fan energy consumption was 15 times higher than the DC motor of the hopper, and coil consumption was still lower than the hopper motor. July and October were the months with more daily power consumption with 448.73 and 424.58Wh which decreases to 369.025 and 345.469Wh, respectively for two fans. On March when only the nursing tank A was fed a 67.62Wh minimum power consumption was monitored. Shorter conveyor time and bigger mass of feed spread to fish instantaneously are demanded by most customers, but airspeed needs to be increased degrading food quality. It is better to convey pellets of high physical quality at higher airspeed, and reduce airspeed for low quality food. It is necessary to increase feeding rate to minimize pellet degradation (Sorensen et al., 2008). Air speed of 28m/s using both fans fed 1.2kg/min for the four tanks but is slower than maximum air speeds of 35m/s of Aquamarine Feed System having 400m length pipelines of 76mm of diameter (Sorensen et al., 2008).

Fish growth and feed intake

Fish mass was the main factor for analysis in this study; in both treatments no significant difference ($P<0.05$) was found. Table 4 presents the fish mean mass at the beginning and end of the experiment, as well as the total biomass produced, feed intake, and feed conversion rate for each tank of the two treatments analyzed in this work. It can be seen that feed conversion rate in the first treatment was 2.14±0.1, while in the second treatment it was 1.6±0.04; consequently a 25.337% (equivalent to 3495.5kg) of food was saved in the second treatment where the feeder with closed loop control was used for fish feeding, despite the growth potential of fish population was supported with the food provided rations, therefore, the feeder with closed loop control provides precise food quantities. These results substantiate the possibility of using a feeder with closed loop control for food management in intensive aquaculture systems, in order to minimize water pollution, save food (reduce the feed conversion and accordingly avoid economic losses rate),

CONCLUSION

A $3500 US automatic feeder used a pneumatic conveying system for dosing dry pellets to four tanks was constructed and evaluated. An embedded system based on the AT 89C51 automated the feeder. The main functions of the embedded system were to provide the monthly quantity of food required per tank, control the weighting mechanism and opening/closing of the motor controlled gates using a laser wireless control. Green and red lasers were used to open gates 1 and 2, respectively. Battery and solar panels were selected to provide a maximum energy consumption of 448.73Wh/day. For three days of autonomy the battery should manage 100 Ah and a 150W solar panel charged the battery. Prototype evaluation in food management studied laminar and turbulent food flow using one and two fans per distribution line.

Airspeed generates turbulent flow, and if high can degrade pellets and wear out the pipeline. Two fans transported the food floating at airspeed of 23m/s as inspected by the vision algorithm and sporadic pellet collisions were measured by the sound meter. Food discharge time decreased from 12seconds to 5 seconds with the use of one and two fans, respectively. Energy consumption decreased by 86% with the use of two fans being the highest tube area occupied of 91.93%. The feeder with closed loop control developed in this work considers temperature conditions and oxygen consumption to determine the most adequate food quantity at each feeding time; based on the feeding table for mirror carp production under intensive conditions, the closed loop control system automatically adjusts the food ration. The system provides new strategies for food management in intensive aquaculture systems. The main benefits obtained using this system are savings in food (reducing the feed conversion rate) and manpower, and diminishing water pollution, therefore avoiding economic loss.

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