Solar energy applications in fixed water recirculation system for aquaculture

Abstract

Recirculating aquaculture systems have proven very successful in resolving problems relating to water shortages for fish production and increased yield as the stocking density is Important. These systems however consume much energy in the running of pumps and heating of water since temperatures play a critical role in the growth of fish. The main objective of this study is to contribute in putting in place a stable automatic temperature-controlled recirculating aquaculture system capable of using water and energy in an efficient manner. The aim was to develop a system that can use just 1000l of water and grow fish to maturity. The system consisted of a 1000l capacity tank, a mechanical filter, a bio rock filter, a de-nitrification tank with water hyacinth, an aeration system, a 12 volt solar pump, a solar water heating system, and computerized automatic controls using the Arduino microprocessor. Everything was powered by 100 Watts solar module connected through a charge controller to a 150AH Battery. One hundred catfish fingerlings were raised in a period of 8 months. Water from the fish tank move by gravity to the mechanical filter before being pumped to the bio rock filter. From the bio rock filter the water moved to the de-nitrification tank. From the de-nitrification tank the automatic control system either sent it back to the fish tank or directed it through the solar water heating if tank temperatures were below 25 degrees C. In order to assess the performance of the system, physical and chemical water parameters were measured with TDS, pH, EC, temperature meter, dissolve oxygen meter and ammonia, nitrite, nitrate and dissolve solids were analysed in the laboratory. Results showed that the average daily weight gain of catfish fingerlings was 0.39±0.28 g and that the physical and chemical water quality parameters were at optimum levels for fish growth.It was concluded that such a system can enable farmers to grow fish to maturity in a region with limited water and energy resources.

Key words: Recirculating aquaculture system, solar water heating, temperature control, automation

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1. Introduction

Fish production in the world is driven by the forces of demand and supply and is the source of food, income, nutrition and livelihood for many people in the world. The united nation member states have set up a sustainable development agenda which is aimed at conducting and contributing aquaculture towards food security (UN,2015).

In Cameroon, as well as in many sub-Saharan countries, fish production does not meet up with the domestic demands, thereby pushing the government to spend much resources in the importation of fish (Business in Cameroon, 2014). The aquaculture sector contributes less than 1 % of national production (NIS.2012). Efforts have been made by the government to improve on productivity but production still remains low (MINEPIA, 2012). Many reasons can be accounted for the low productivity but poor techniques employed play a major role (Pitt and Conover, 1996). The lack of water resources and other environmental problems like low temperatures seriously affect fish production.

Recirculating aquaculture systems (RAS) have been developed to overcome pollution concerns and stocking capacity. RAS offers several advantages over traditional flow-through systems mostly practiced in Cameroon. RAS uses 90 % to 99 % less water and land area compared with pond aquaculture systems (Ebeling and Timmons, 2012). The advancement of RAS technology and advantages over the flow through systems has led to its increasing use, especially among countries that place high values on minimizing environmental impacts and in urban areas where space is limiting (Barthelme *et al.*, 2017).

RAS is mostly used in Cameroon for fish hatcheries and not for production. This is because they the system very expensive to install and run. There is little access of electricity to most areas in Cameroon. Solar energy use can be a solution for energy requirement for these systems. Studies have been attempted on the design and construction of small scale RAS in using solar energy in the renewable energy laboratory of the university of Dschang (Wirsiy, 2017). The system function well but the growth rate of fish was relatively low. Amongst the factors identified hindering fish growth, low water temperature in the tank was the main.

Fish generally show temperature optima for growth and survival (Brett, 1979; Gadomski and Caddell, 1991). The combined effects of size and temperature on growth have been described for several fish species (Brett, 1979; Fonds et al., 1992). Studies carried out on African catfish, Clarias *gariepinus* have shown that their growth rate increases with increased in temperatures. High growth rates have been recorded between 25 and 33°C and the best growth rate was obtained at 30°C (Britz & Hecht, 1987). The effect of solar-induced temperature on the growth performance of African sharp tooth catfish (*Clarias gariepinus*) has been studied in the investigation revealed that water temperature was significantly different among treatments ($p<0.05$) and the highest value was observed in treatment 3 (30.91±1.60 ℃), followed by treatment 1 (29.19±1.54 ℃) and treatment 2 (27.58±1.58 ℃), respectively (Wirawut, *et al*., 2015).

Results of the experiment further showed that the differences in temperatures affected the growth and survival rate of the fishes. After 90 days of culture, fishes in treatment 1 had significantly higher weight (298.75±4.32 g/fish), growth rate (3.32±0.05 g/day) and survival rate (95.0±2.0) than treatment 2 (198.40±5.25g/fish, 2.20±0.06 g/day and 89.0±2.0) and treatment 3 (198.40±5.25 g/fish, 2.20±0.06 g/day and 87.6±2.1) ($p<0.05$) (Wirawut, *et al*., 2015).

Many methods have also been used to raised water temperatures of fish tank amongst which we have active and passive solar collectors. Most of the system temperatures have been successfully controlled with green house of Fuller (2007). But managing other parameters in the greenhouse are difficult.

The main objective of this work was to develop a low cost system that would use a limited amount of water through recirculation system to grow fish to maturity while exploiting solar energy for pumping, heating and re-oxygenation of the water. Such a system will also be very useful especially in arid land where water and energy are limiting.

2. Materials and method

This work was carried out in the Renewable energy laboratory of the University of Dschang in Cameroon. The experimental unit was made of a well-designed recirculating aquaculture system consisting of 1000 l transparent Plexiglas fish tank, 20 l mechanical filter, 50 l pump tank, 200 l biological filter with scoria rock as the filter media and 100 l denitrification tank containing

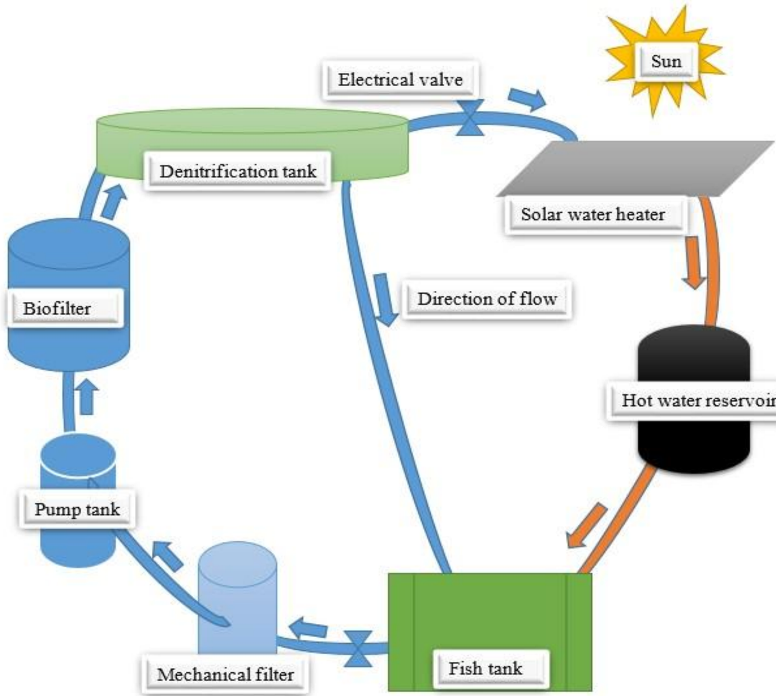

Fig. 1 System layout for the designed acquaponic system

water hyacinth plants. Energy for running a 12 V DC pump was provided by a 200 w solar panel accumulated in a 150 AH deep cycle battery.

Solar heater design and construction

A flat plate solar collector was chosen for this system. The methods employed in designing solar water heaters for swimming pools was adopted in designing this collector which takes into consideration the surface area of tank, volume and initial and final temperature of the water. (Cromer, 1994). Copper tubes of 14 mm were serpent at 10 cm apart inside a 150 cm wooden box and casted with aluminum. The internal surface was painted black and 5mm glass was used at the top of the collector. Water flows into the collector by gravity from the biological filter tank (Fig2). The flow of hot water from the collector to the reservoir is controlled by a temperature sensor and an electrical valve to the hot water reservoir.

System operation

One hundred catfish fingerlings were raised in a period of 8 months. Water from the fish tank move by gravity to the mechanical filter before being pumped to the bio rock filter. From the bio rock filter the water moved to the de-nitrification tank. From the de-nitrification tank the automatic control system either sent it back to the fish tank or directed it through the solar water heating if tank temperatures were below 25 degrees C. In order to assess the performance of the system, physical and chemical water parameters were measured with TDS, pH, EC, temperature meter, dissolve oxygen meter and ammonia, nitrite, nitrate and dissolve solids were analysed in the laboratory.

Automation

The system was automated with the help of Arduino UNO microprocessor. The Arduino card with the different input and output pins (Figure 2a) was used. A waterproof digital thermal probe sensors (DTPS) (figure 2b) was used to acquire instantaneous water temperatures. Two of the DTPS were intended to give the average water temperatures in the fish tank and one to give temperature values of the solar water heater (SWH). The temperature values were displayed on a liquid chrystal display screen (LCD). Temperatures values from the various sensors were stored on a smart disc (SD) using a real time clock (RTC) that records data on real time on an excel sheet (Figure 1c). Electrical solenoid valves (EV) were used to control the flow of hot water from the SWH. An electrical float switch (EFS) was used to control the level of the water in the pump tank. A backup water heating coil (WHC) was controlled by a 12-V relay which was commended by the microprocessor.

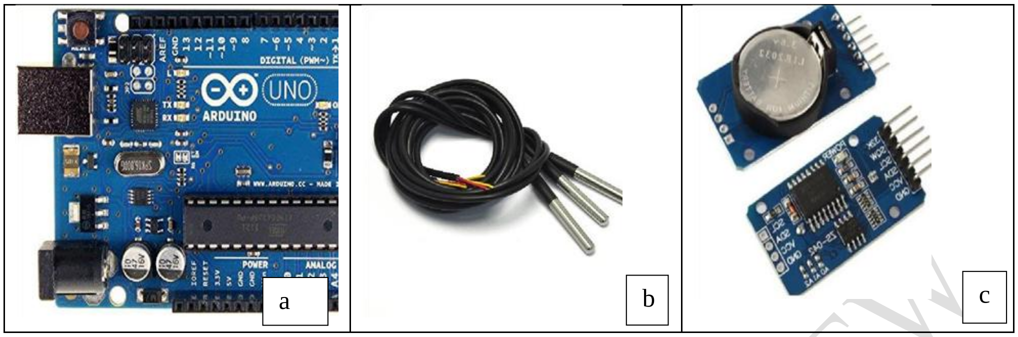

Figure 2: Arduino components for programing (a) Arduino board;(b) digital temperature probe; (c) real time clock

The Arduino programming language was used for coding. Each component was coded and tested separately using a test board. A flow chart for the running of the program was drawn using word paint. The system was setup including the backup electrical water heating element. The program was run for 8months days. The program was set to maintain water temperatures in the fish tank between 27 and 30 °C which is the temperature range for optimum catfish growth. The system was then carefully monitored to avoid extreme cases. This parameter was used to conclude for the effectiveness of the program.

1.1.1 Flow calculation

The procedure for flow calculations should initially focus on the maximum feeding rate (kg feed/day), maximum biomass and culture volume and the waste production per kg feed. For flow rate calculations and biofilter design, the concept presented by Liao and Mayo (1972, 1974) is often cited. They described the concentration of a metabolite at the outlet of a fish culture tank in a recirculation system as a proportion to the concentration of the same metabolite in a system without recirculation equation (2.4). other authors like Timmons et al. (2001); Summerfelt *et al*. (2001) use metabolites accumulation factor in estimating the quantity of metabolites at the outlet of the fish tank equation (2.5)

$$C = \frac{1}{1 - R + R * TE} \qquad (2.4)$$

Where:

C = allowable waste concentration in the fish tank effluent (g/m3)/single pass waste concentration (g/m3);

R =factor which is based on the fraction of the water flow that is reused;

TE = the treatment efficiency (decimal fraction);

$$\text{Waste}_{\text{out}} = \left(\frac{1}{1-\text{R}*\text{TE}}\right) * \left(\left(\frac{\text{Pwaste}}{\text{Q}}\right) + (1-\text{R}) * (\text{Waste}_{\text{new}})\right)$$ (**Error! No text of specified style in document.**.1)

Where = $Waste_{out}$ -TAN concentration in the fish tank effluent;
Pwaste = waste (metabolite) concentration in the fish tank effluent (g/m3);
$\text{Waste}_{\text{new}}$ = concentration of a metabolite in the make-up water (g/m3);
Q = water flow, for TAN the water flow recirculated across the biofilter (m3/day).
Knowing that many RAS are operated at a water recycling percentage of 96% or more (R 0.96), Timmons *et al*. (2002) use Eq. (2.6), (2.7) and (2.8) in arriving at the flow calculation.

$$C_{TAN,out} = \left(\frac{1}{TE}\right) * \left(\frac{P_{TAN}}{Q}\right)$$ (**Error! No text of specified style in document.**.2)

$$C_{Treatment,out} = C_{Treatment,in} + TE\left(C_{Treament,best} - C_{Treatment,in}\right)$$ (**Error! No text of specified style in document.**.3)

$$Q = \frac{P_{TAN}}{TE * C_{TAN,out}} = \frac{P_{TAN}}{C_{TAN,out} - C_{TAN,in}}$$ (**Error! No text of specified style in document.**.4)

Where
$C_{TAN,\,out}$ = TAN concentration in the fish tank effluent (g/m3)
$C_{TAN,\,in}$ = filter effluent concentration and fish tank influent concentration
$C_{treatment,\,best,\,TAN}$ = 0 (Timmons *et al*., 2002)
P_{TAN} = production of TAN (g/day)
$C_{TAN,\,in}$ = TAN concentration of the fish tank influent (g/m3)

1.1.2 Dimensioning/sizing a biofilter

For dimensioning or sizing a trickling filter, only limited information is available. In practice, TAN removal efficiency is often empirically determined for a fixed set of successful conditions such as fish species, feed load, filter height, filter media type, hydraulic surface load, suspended solids unit and TAN influent concentration. When the TAN removal efficiency for a certain trickling filter influent concentration is known, it is based on data for a fixed filter height, media type, hydraulic surface load, TAN removal rate and temperature. The required total nitrification surface area (A, m2); Eq. (2.6)) is calculated from the trickling filter TAN load (P_{TAN} load, trickling filter, g/day) and the estimated nitrification rate (r_{TAN}, g TAN/m2/day). The bioreactor volume (V trickling filter, m^3; Eq. (2.9)) is a function of the total filter surface area (A, m^2) and the specific surface area (a in m^2/m^3) biofilter media) of the filter media. The shape of the reactor (Eq. (210)– (2.11) depends on the hydraulic surface load (HSL, m3/m2/ day) (Losordo et al., 2000; Wheaton *et al*., 1994).

$$A_{Trickling\ filter}(m^2) = \frac{P_{TAN\ load\ \ filter}\left(\frac{g}{day}\right)}{r_{TAN}\ \frac{g}{m^2}/day}$$ **(Error! No text of specified style in document.**.5)

$$\mathrm{V_{trickling\ filter}}(\mathrm{m^3}) = \frac{\mathrm{A_{trick\ filter}}(\mathrm{m^2})}{\mathrm{a}\left(\frac{\mathrm{m^2}}{\mathrm{m^3 biological}}\mathrm{filter}\right)}$$ **(Error! No text of specified style in document.**.6)

$$\mathrm{S_{cross-sectional\ area}}(\mathrm{m^2}) = \frac{(\mathrm{Q_{trickling\ filter}}\left(\frac{\mathrm{m^3}}{\mathrm{day}}\right)}{\left(\mathrm{HSL}\left(\frac{\frac{\mathrm{m^3}}{\mathrm{m^2}}}{\mathrm{day}}\right)\right)}$$ **(Error! No text of specified style in document.**.7)

$$D_{diameters}(m) = 2\sqrt{\frac{S_{crossectional\ area}(m^2)}{3.1416}}$$ **(Error! No text of specified style in document.**.8)

$$H_{height}(m) = \frac{V_{trickling\ filter}(m^3)}{S_{crossectional\ area}(m^2)}$$ **(Error! No text of specified style in document.**.9)

1.1.3 Empirical relations

Liao and Mayo (1974) observed that TAN removal rate (NAR, g TAN/m2/day) is a function of the TAN loading rate (AL, g TAN/m2/day) and media retention time (tm = Vmedia (m3)/void fraction/flow rate (m3/h): NAR = 0.96ALtm). This equation was rearranged in: NAR/AL = EA (filter efficiency) = 0.96 tm. They showed nine steps in arriving at a trickling filter design. At the start of the design procedure, the fraction (R) of the water flow rate that is reused is assumed to be known.

Step 1: Determination of water flow (m^3/day) needed for O2 requirement fish culture tank and TAN control. Determination of allowable TAN concentration in the fish tank ($C_{limit,TAN}$). When oxygen flow is chosen for filter design, the single pass concentration of TAN has to be calculated for this flow.

Step 2: Determine the ammonia accumulation factor (C) due to recirculation:

$$C = \frac{(C_{limit,TAN})}{C_{TAN}}$$ **(Error! No text of specified style in document.**.10)

Where:

$C_{limit,\ TAN}$ = allowable ammonia concentration (g/m^3);

C_{TAN} = Single pass ammonia concentration (g/m^3);
Step 3: Determine the filter efficiency (E)

$$E = \frac{1+CR-C}{CR}$$ **(Error! No text of specified style in document.**.11)

Where:
E = filter efficiency (decimal fraction);
C = ammonia accumulation factor;
R = recycle percentage (as decimal).
Step 4: Calculate the total ammonia load filter (g TAN/day). This is done by considering that total ammonia load is equal to total ammonia production.

Step 5: Calculate filter retention needed to achieve ammonia removal of E at a certain temperature

$$t_m = \frac{E}{9.8(T)-21.7}$$ **(Error! No text of specified style in document.**.12)

Where:
E = filter efficiency (%);
t_m = media retention time (h);
T = temperature (°C)
Step 6: Calculate filter volume:

$$V = (R * t_m)\left(\frac{day}{24h}\right)\left(\frac{1}{V_v}\right)$$ **(Error! No text of specified style in document.**.13)

Where:
V = Filter volume (m^3)
R = flow rate (m^3/day)
V_v = media void volume (fraction)
Step 7: Filter surface area (A, m^2)

$$A = V * Ss$$ **(Error! No text of specified style in document.**.14)

Where;
Ss = specific surface area filter media (m^2/m^3)
Step 8: Check if the TAN load is less than 0.977 g/m^2/day
Step 9: Determine the filter dimensions.

Energy in Recirculating Aquaculture System

Continuous energy source and supply is the prerequisite for RAS. It can be supplied by national line or using renewable energy sources such wind and solar energy. Energy is needed for:

- pumping of liquids (water and air) from and into the system;
- heating of water; and
- functioning of some components such as fans, automated components and rotatory organs in some filters (RBC).

1.2.1 Pumps for the recirculating aquaculture system

Pumps are used for pumping of liquids in the RAS. Conditions for selecting aquaculture pumps are:

- the total head or pressure against which it must operate,
- the desired flowrate,
- the suction lift, and
- characteristics of the fluid (water for this case).

Types of pumps

Two types of pumps that are commonly used in aquaculture are the centrifugal and the axial flow propeller pumps.

- **Centrifugal**

Centrifugal pumps use centrifugal force to move water from one point to another and to overcome resistance to its flow. In its simplest form, this pump consists of an impeller fixed on a rotating shaft within a volute-type (spiral) casing. Water enters at the centre of the impeller and is forced to the outer edge at a high velocity by the rotating impeller. The water is discharged by centrifugal force into the casing where the high velocity head is converted to pressure head. The type of centrifugal pump that has been design for low-lift operation is the horizontal PTO-driven centrifugal pump. These types of pumps are less efficient but still maintain the capability of pumping large volumes of water. They are portable and often fit into a flexible management plan for aquaculture production.

1.2.2 Biofilter tank design

The type of filter chosen for this system was the trickling filter. The assumptions for the design of this filter were:

- Stocking density of 30 kg/m3 (Thomas *et al.*,1999),
- Feeding rate of 5 % daily weight at 32 % crude protein;
- Flow rate of 10.16 m3 through the system;
- Recirculation rate of 90 %
- allowable ammonia of 7 g/day
- Total ammonia load is assumed to be equal to total ammonia production

- Scoria rock is the filtering material

The empirical equations proposed by Liao and Mayo (1974) in section 2.4.3 were used in calculating the TAN loading rate. Equation 1 was used in calculating the ammonia accumulation factor. The value for the accumulation factor was used in determining the total ammonia load. Equation 2.15 was used in calculating the filter efficiency. Equation 2.16 was used to calculate the filter retention time at 22 °C. The filter volume and surface area were empirically determined using equation 2.17 and 2.18. Scoria rock of 50 % porosity and specific surface area of 127 m^3/m^2 was also used (Jaff, 2015). Equation 3.4 was used to calculate the TAN removal rate (Nar).

$$Nar = 0.96Al * tm \qquad (3.4)$$

Where:
Nar = TAN removal rate (g/m2/day)
Al = total ammonia load (g TAN/day)
tm = filter retention time

Using the above filter empirical equations, the trickling filter surface area and volume were calculated using equation 2.9 and 2.10 respectively. The trickling filter cross-sectional area, diameter and height were also calculated using equations 2.11, 2.12 and 2.13.
The height and the diameter of the filter were the parameters taken into consideration in choosing a container for biofilter construction.

1.2.3 Mechanical clarification and denitrification tank design

The design for the mechanical clarification tank is shown in figure 3. It was designed to have an upward movement of water. The determination of the diameter and thickness of the mesh used was done by experimentation that is pouring water containing solid particles on the mesh and evaluating the quantity of solid particles present in the recollected clear water.

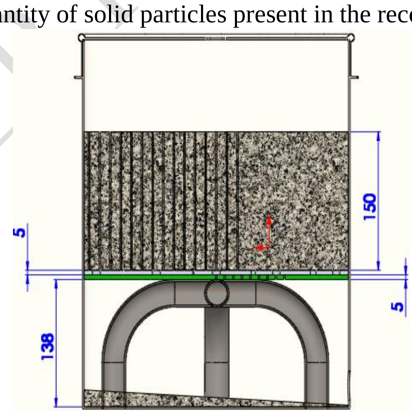

Figure Error! No text of specified style in document.**: Mechanical filter tank design showing the different layers with adopted dimensions**

Water hyacinth plant (*Eichhornia crassipes*) was used as a means of reducing water nitrate concentration. This plant was chosen because of its high nitrate uptake and floating ability in water (Jaff, 2015). The possibility of the plant to carry out photosynthesis was taken into account in choosing a vessel to host it.

1.2.4 Solar energy system design

❖ **Determination of power consumption demand**

A pump was chosen based on the hydraulic needs of the system. The energy requirement and the time of functioning of the pump was used in calculating the power consumption demand of the system. All other electrical components that could consume energy were taken into account. A load sizing worksheet was used in determining the power demand of the system (table 1).

Table 1: load sizing worksheet

DC appliances	Power (W)	Hours per day (H)	quantity	Energy /day (WH/day)	Energy/week (WH/week)
pump	85	7	1	595	4165
Arduino board	1	24	1	24	168
Total					4333

The total energy needed per week (E/week) for the DC load was calculated using equation 3.5

$$\frac{E}{week} = \frac{WH}{week} * f \qquad (3.5)$$

Where f is a factor to compensate for losses during battery charging and its value is 1.2. The amp-hour require per week is was calculated using equation 3.6. and the average amp-hour per day was obtained by dividing equation 3.6 by 7.

$$\frac{Amphour}{week} = \frac{\frac{WH}{week}}{V} \qquad (3.6)$$

Where:

V = voltage of the battery bank (volts)

❖ **Battery bank sizing**

The assumptions taken here in sizing the battery were that:

- it should have an autonomy (A) of two days;
- a discharge depth (d) of 50 % and;
- the ambient temperature multiplier (t) of 1.04 at 21 °C.

The required amp-hour of the battery was calculated using equation 3.7

$$Amphour(bat) = \frac{\frac{amphour}{day} * A * t}{d} \qquad (3.7)$$

Where amp-hour(bat) = total required system amp-hour

The number of the batteries required in parallel were obtained using equation 3.8 and in series by the quotient of the system nominal voltage (12 V) to the battery voltage. The total number of batteries were obtained by product of the batteries in series and parallel. A solar battery of 200 AH was selected for the calculations

$$\text{Number of batteries in parellel} = \frac{\text{required amphour}}{\text{power rating of battery}} \quad \text{(Error! No text of specified style in document..Error! Bookma}$$

❖ **Solar array sizing**

The solar irradiation value used for the design is that of the month of August for Dschang and is 3.9 kWH/m2/day (PVGIS, 2012) or approximately 4 h of daily Peak Sun Hours (PSH). The output current (Ic) i.e. the total amperage requirement of the array was calculated using equation 3.9

$$Ic\ (A) = \frac{AH/day}{PSH(Hours)} \qquad (3.9)$$

The selected module for the design was a 200 W with a 3 % power tolerance, a short-circuit current (I_{out}) of 5.77 A and working current of 5.41 A giving the adjusted current (current output for each module) of 5.44 A. The number of module in an array in series is given by equation 3.10 and the number in parallel is given by equation 3.11. The total number of modules was obtained by the product of the module in series and parallel.

$$Number\ of\ module\ in\ series = \frac{system\ voltage}{norminal\ operating\ voltage} \qquad (3.10)$$

$$Number\ of\ module\ in\ parellel = \frac{PV\ array\ output\ current\ (Ic)}{current\ output\ for\ each\ module} \qquad 3.11)$$

❖ **Sizing charge controller**

The charge controller was sized to withstand at least 125 % of the short circuit current and withstanding the open circuit voltage of the array. The current value of the charge controller needed was calculated using equation 3.12

$$\boldsymbol{size\ of\ the\ controler\ (A) = 1.25 * I_{out\ (A)} * number\ of\ modules} \qquad (3.12)$$

1.2.5 Hydraulic design

The system was designed such that water circulates by pumping and by gravity**.** The vessel communication principle was applied between the fish tank and the mechanical filtration tank. PVC pipes were used for water circulation in the system but for a flexible pipe that was used between the pump tank and the biofilter tank. In order to select the pump, the TDH was calculated using equation 3.13 Energy saving, system flow rate and pump availability are other aspects taken into account in selecting the pump.

$$TDH = H + \Delta H \qquad (3.13)$$

Where:

H = vertical height from the soil (m)

ΔH = frictional losses (m). The value of ΔH is calculated using equation 3.14

$$\Delta H = 10.65\left(\frac{Q^{1.85}}{(K'^{1.85} * D^{4.87}}\right)L \qquad (3.14)$$

Where:
Q = flow rate (m3/s);
D = internal diameter of the pipe (m);
L= total length of the pipe (m);
K'= Hazen-William coefficient (150 for PVC and plastic pipes)

Fish growth monitor and test

Fish was weighted using an electronic balance. The length of the fish also measured using measuring tape. Forty-two fish of 206.4±12 g average weight was cultured in the system. Fish was fed with extruded pelleted floating feed using the recommended daily ration table for North African catfish, *Clarias gariepinus*. Water quality parameters including pH, dissolve oxygen ammonia, nitrite and nitride were also closely monitored using appropriate probe meters and tests. Fish was put in a temperature controlled environment for the same period of three weeks after which it was weighed. The water quality parameters were still closely monitored. The weight gain between the two environments was compared using SPSS software with paired sample T-test.

3. Results and discussion

3.1 Results

The flow of water through the various components of the system is shown in figure 4.

Figure 4: flow of water within the various components (a) movement of cold water from the fish tank and entry of hot water into the tank (b) the realized prototype showing hot water reservoir, solar collector, fish tank filters and other electrical components

The flow diagram showing the automation program is as shown in figure 3 showing the partway of the program.

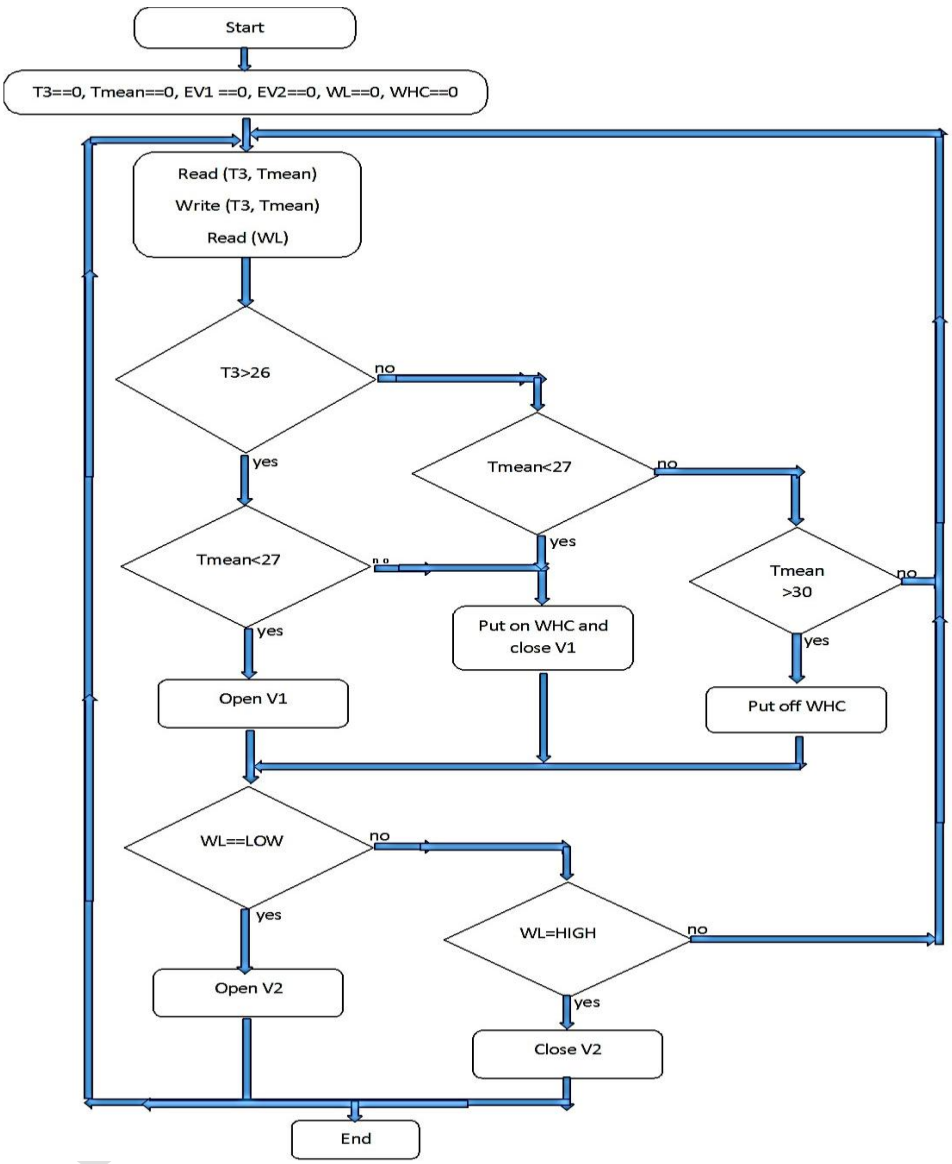

Figure 5: Flow chart design for automation in temperature and water level regulation (Tmean is the average temperatures in the fish tank given by two temperature sensors T1 and T2, T3 temperature of water in the SWH and V1 and V2 are the electrical valves)

The performance of the solar water collector without the backup is as shown in figure 4 during testing. Meanwhile figure 5 shows the variation in temperatures of water in the fish tank for 21 days (recorded at 30 minutes’ interval) being automatically controlled by the microprocessor and its components.

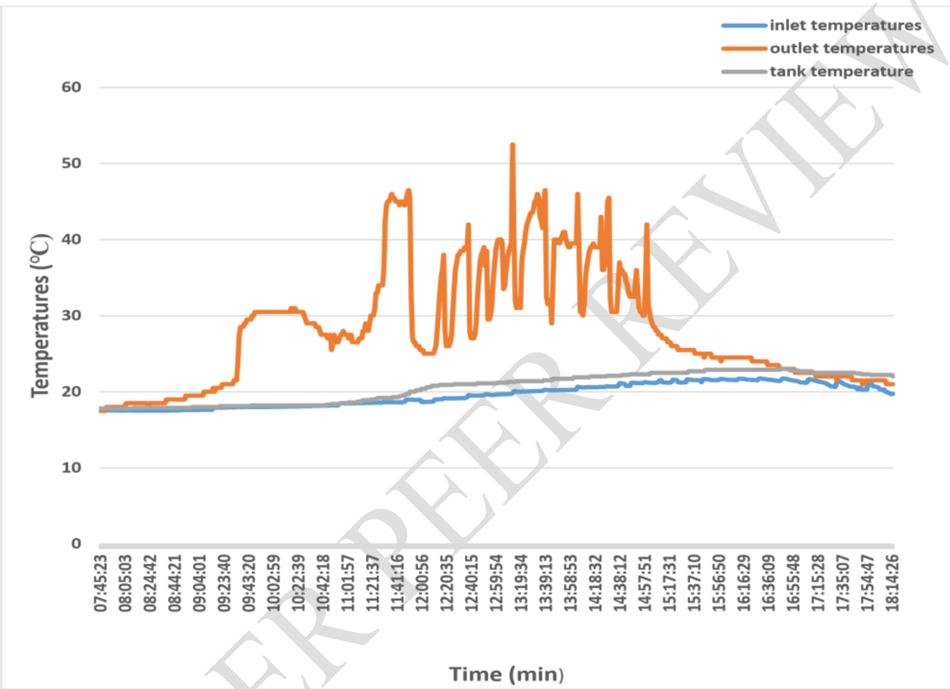

Figure 6: variation of temperature of water from the SWH collector (considering inlet and outlet temperatures) and the overall effect on the total volume of water in the tank at a fixed flow rate of 1.58 l/min an average sunny day

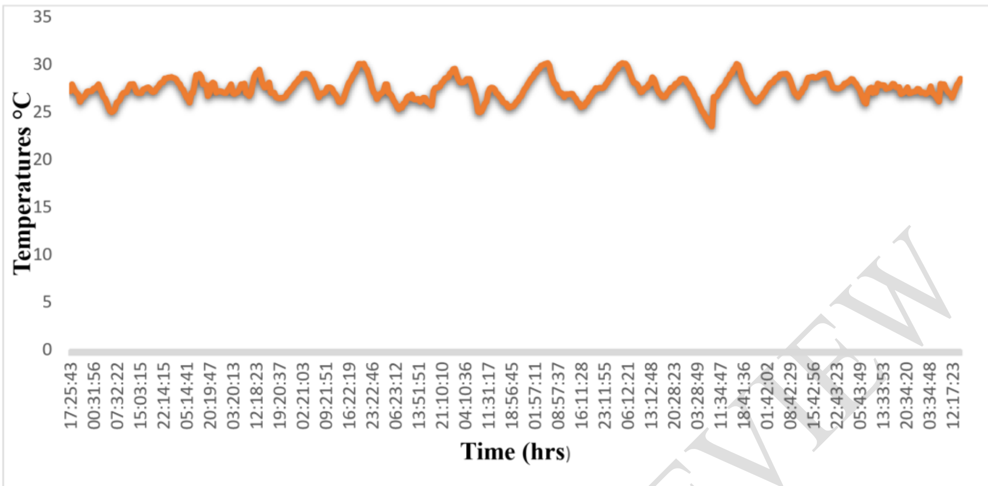

Figure 7 Temperature variation in fish tank being automatically controlled with solar heater and backup heater recorded continuously for 21 days in a data logger

The fish growth performance parameters for both heated and non-heated system is as shown in table 1. While the test statistics for heated and non-heated (paid sample t-test) is as shown in table 2.

Table 2: fish growth performance parameters

Parameters	**Control periods**		
	Initial	**Non heated**	**Heated**
TL (cm)	28.43±4.09	31.45±4.09	33.84±3.09
W (g)	206. 4±12.10	238.40±77.14	330.83±101.53
WG (g)		32.311±17.70	91.62±26.32
DWG (g)		1.54±0.84	4.36±1.23
SWG (g)		1.52±3.10	4.40±1.61
SR (%)		100	100
K		0.77±0.001	0.86±0.003

Table 3: Statistical Comparison between heated and non-heated in the system

	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
	lower	upper			
Heated - Non heated	53.5343362	65.0914703	20.962	30	.000

3.2 Discussion

Water from the bio filter is collected in the denitrification tank (figure 2). There are two exits from the denitrification tank; one that supplies the fish tank directly and the other the supplies the solar water heater. There is an electrical valve before the SWH that controls the flow of water commanded by the Arduino microcontroller. Hot water from the heater is collected first in the reservoir which in turn supplies the fish tank. The backup electrical heating coil is uses to raise the temperatures further when need arises. The cycle of water continues.

The programming had to perform the following tasks:

- Read and display temperatures in the fish tank (Tmean) and the temperatures of SWH (T3);
- Provide the control of temperatures of water in the fish tank by maintaining it within a particularly range ($27 \leq \text{Tmean} \leq 30$);
- Provide the control of the flow of water in and out of the fish tank and finally;
- Store the temperature data in an SD card as means of data acquisition and verification of problems

The performance solar water heater in raising water temperatures is as shown in figure 4. From the maximum and minimum values obtained within the fish tank, it can be noticed that temperatures are increased by 5.2 ℃ which doubles the increase without heating. This further shows how performant the SWH is in increasing the water temperatures in the fish tank during the day not withstanding that the tank is open and oxygenation is by gravity which increased heat losses. Also from the graph, we can observe that temperatures from the SWH drop to a very low value at evening due do the departure of solar radiations which implies that the heater will be acting as coolant at this time. This is one the reason why an EV was programmed to cut off the flow of water entering the heater at temperatures less than 26 ℃.

Automation in the system worked as programed as can be seen on the graph (figure 5) where temperatures averagely vary between 27 and 30 ℃ for the 21 days. The data here was recorded at 30 minutes' intervals in the SD card. The drop in temperatures to 25 ℃ observed in some days (4 6 hours) was due to over discharging of the battery there by not providing enough energy for the backup heater to take relay.

The growth parameters of weight gain and survival rate was performant as seen in table 1. Table 2 also shows the statistical analyses with SPSS between the heated and non-heated system. It shows from the table that there exist a significance difference between the heated temperature control and non-heated (non-temperature control) periods. This further implies that temperatures were the major hindrance to growth of fish in the system in the previous attempted experiments in the same laboratory as daily weight gain of 0.33 gram was obtained (Wirsiy, 2017). The average weight gain obtained from the heated is greater than that abstained by Anyanwu *et al.* (2012) for their experiment on catfish fingerlings as their values ranged from 2.71 to 2.96 for four experimental tanks with temperatures greater than 25 °C. it is also different from the daily weight gain of 3.32±0.05 g obtained by (Wirawut, *et al*., 2015) in their experiment on catfish in a greenhouse with temperatures at 30. This can be explained because other parameters than temperature need to control if not will reduce growth rate.

The system is thus efficient. With this growth rate obtained, we can say that it will take a very short period of time to grow fish in this system. The system is therefore very stable and easy to manipulate unlike solar heated systems in a green which are very complicated in controlling other parameters (aeration, humidity) inside the house.

4. Conclusion

The Solar water heater together with the backup heater were successfully designed, constructed and installed in the existing system. The automated system was also successfully designed and the circuit built using Arduino microprocessor and other sensors. Solar thermal and electrical energy were both exploited in this system to run the system and for heating of water. Solar water heater contributed a daily increase of more than 5.2 ℃ there by raising the temperature in the fish tank during the day The automation is very efficient as it regulates the temperatures within the instructed values and water level thereby making the environment favorable for fish growth. There exists a significance between the heated and non-heated periods of growth in fish leading to the conclusion that temperatures were the actual growth retarding factor in the system.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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