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Design and Development of User-Friendly Vertical Aquaponics Set-up for Ornamental Fish and Plants

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Abstract

One vertical aquaponics unit following the principle of Nutrient Film Technique (NFT) has been designed and developed at ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar centre of All India Coordinated Research Project on Plasticulture Engineering in Agriculture Structures and Environment Management (AICRP on PEASEM). The developed unit is constructed using three major components, viz., fish tank/ aquarium tank (0.127 m^3), vertical hydroponic pipe (Ø0.16×1.5 m) and the water distribution system. The unit experimented with 30 numbers of Guppy fish (*Poecilia reticulata*) in 0.1 cubic meters of water and 6 numbers of Petunia plant (*Petunia × hybrida*) and 6 numbers of Zinnia plant (*Zinnia angustifolia*) in 204 CC hydroponics cups arranged at 20° from the vertical axis on a PVC pipe. The quad channel sprinkler is fixed inside the pipe at the top surface. The water dispersion efficiency concerning the availability of nutrient-rich water at the roots of the plants for its flowering has been evaluated in the present study. The optimum water quality and flower production from the plants were achieved at 200 LPH flow rate from the fish tank. At this hydrolic loading rate, maximum plant length & spread were observed among the three replications . The length & spread for *Zinnia angustifolia* and *Petunia x hybrida* were 37.17±4.27 cm & 39.54±7.45 cm, and 33.43±2.53 cm & 29.58±7.26 cm respectively. There was no significant difference ($p>0.05$) in the water quality parameters at 200 & 250 LPH flow rates in the vertical aquaponics system. The cost of one unit is calculated to be INR 7000, with approximately a 10-20% price reduction in case of mass production. The newly developed integrated system of aquarium is designed for peri-urban and urban hobby farming as well as home decoration.

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Introduction

Aquaponics is the integration of aquaculture and hydroponics into one production system. The only input in aquaponics is the food introduced for fish, which is biologically converted and released to the rearing media as nitrate and nitrites. As ammonia-rich urine and faecal matter itself, can be toxic to plants and fish, the nitrified solution from the biofilter acts as a nutrient for the plants in the system.[1] This makes this technology sustainable and very efficient in the conservation of resources.

Another aspect of resource conservation is the compulsion for optimum utilization of land as recently the majority of this resource in the urban areas is being occupied by skyscrapers or industrial factories.[2] As agriculture needs to find its position in urban life, for us to survive and fulfil our demands for food, there will always be the need to find a sustainable, feasible and easily manageable technology such as aquaponics farming. Additionally, some experimental pilot scale NFT aquaponics studies also suggested the successful viability of such systems at different scales of operation.[3,4]

Vertical farming has proven its merits over the years of urbanization by very minimal land utilization.[5] Vertical farming in the form of hydroponics, aeroponics and cascade gardening is a prime example of the success of this technology. The vertical aquaponics system is a method of aquaponics where plants are grown in vertical position above the fish tank. It applies the method of nutrient film technique (NFT) of aquaponics, in which the plants are grown in a long narrow pipe or channel. The advantage of the vertical towering is that, one can have crops effectively growing above each other utilizing comparatively less space.[6] The nutrient-rich water trickles through the roots of the plants, and at the same time gathers oxygen from the air as it falls back into the tank. The small-scale vertical aquaponics are suitable for indoor gardening and aqua-decoration as they are genrally maintaince free and adds vegetation to the modern home interiors. Also, a study suggests the indoor plants help in improving the air quality and ambience of the home, which inturn improves lifestyle.[7] The ornamental fish is also considered to increase prosperity of the house.[8] Such aspects would aggreviate the demand of such space efficent technology for multi dimenational ecosystem culture for indoor recreation and awareness of sustaining life in the present mechanized society.[9]

With the objective of the conservation of both space and energy, the current design of the vertical-type small-scale aquaponics setup has been developed and tested for sustainability and socio-economic viability. Additionally, these small setups can be implemented in household decoration to bring forward awareness of aquaponics farming in the urban community. The optimum flow condition for this type of domestic aquaponic system is derived in this experiment.

Material and Methods

Initial Experiment

A preliminary trial experiment was conducted using a prototype model of the vertical aquaponics setup. The setup comprised of a truncated cone-shaped PP (Poly-Propylene) tub with a bottom diameter of 400 mm, top diameter of 600 mm and height of 300 mm. The tub was used as the fish tank with an operational water volume of 45 L. Plantation was done on a vertical hydroponis of Ø160 mm PVC pipe with a 4 kg/cm^2 load capacity. The height of the pipe was 1.37 m. This thermoplastic PVC pipe was heated and the plantation holes were made by reshaping the side walls at 20^0 inclination from vertical axis. The pump used for water circulation and sprinkle was a generic 30 W centrifugal submersible pump of ABS plastic body. The pump had a multistage adjustable flow regulator. The experiment was conducted using 20 numbers of Guppy fish (*Poecilia reticulata*), and 6 numbers of Petunia (*Petunia × hybrid*) & 6 numbers of Zinnia (*Zinnia angustifolia*) plant for a period of one month during August – September, 2022.

Working Method

Nutrient rich water from the fish tub was pumped to the top of the vertical plantation pipe through a 12 mm ID silicone pipe. The top of the pipe was capped and water was made to squirt through small holes in the silicon tube near the top of it. The working layout is given in Figure 1(a). The experimental set-up from field condition is given in Figure 1(b).

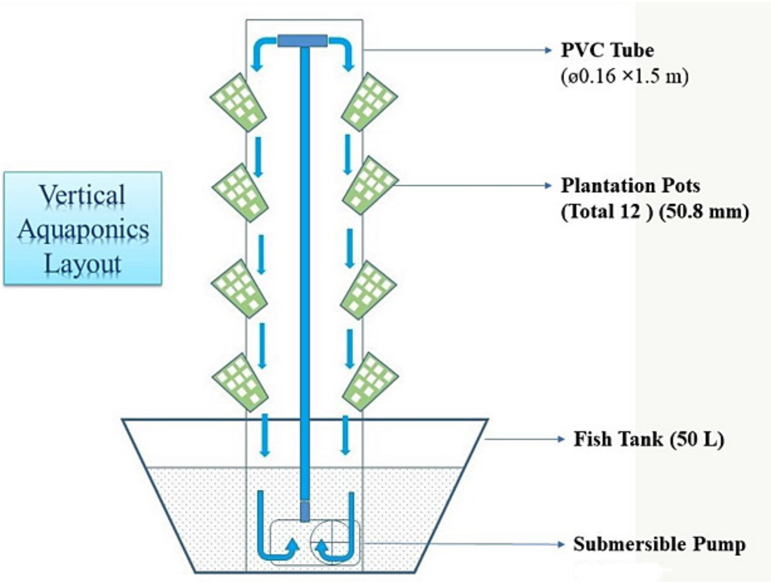


Fig. 1(a): Vertical aquaponics layout

Fig. 1(b): Vertical aquaponics set-up in field condition

Present Experiment

The simple aquaponics setup is designed keeping reliability and self-maintaining properties in mind. The main components of this system are:

Fish Tank

It is a glass rectangular tank (0.6 × 0.46 × 0.46 m) for 100 L operational water volume. The side walls are 5 mm thick annealed glass. For the calculation of the wall thickness, the compressive load exerted by the water is calculated considering the safety factor (FoS) of 3.8[10] for this type of container, the load capacity is calculated using,

$f_s = \sigma / F$

Where, fs = Factor of Safety (FoS)

σ = Yield strength of the material

F = Design load

$t = FL/\sqrt[3]{(4E_b \times w \times y)}$

Where, t = Glass thickness

L = Length of the fish tank

E_b = Bending Modulus

w = Width of the glass tank

y = Deflection at the load point

The design analysis in Figure 2 shows the tank and material are within the hydrostatic load tolerance limit.

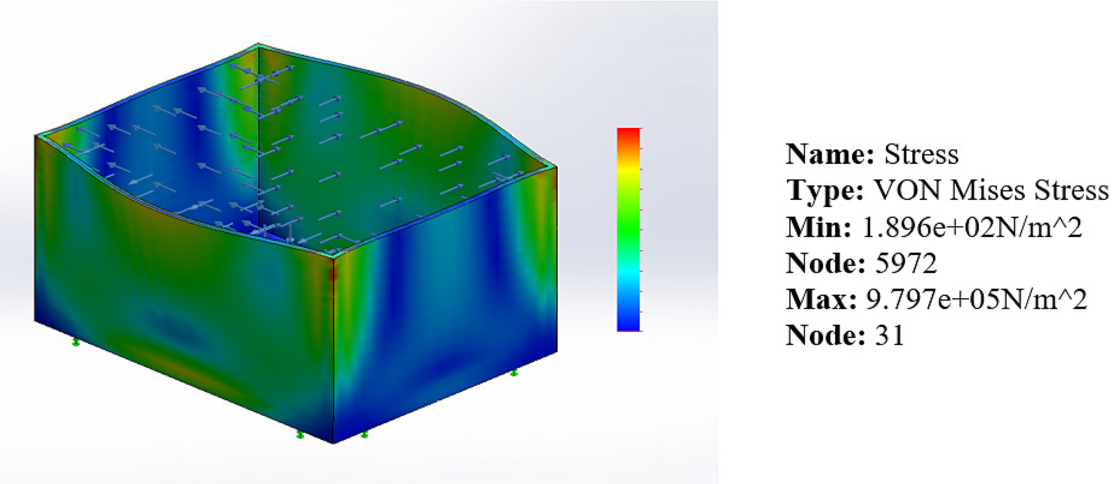
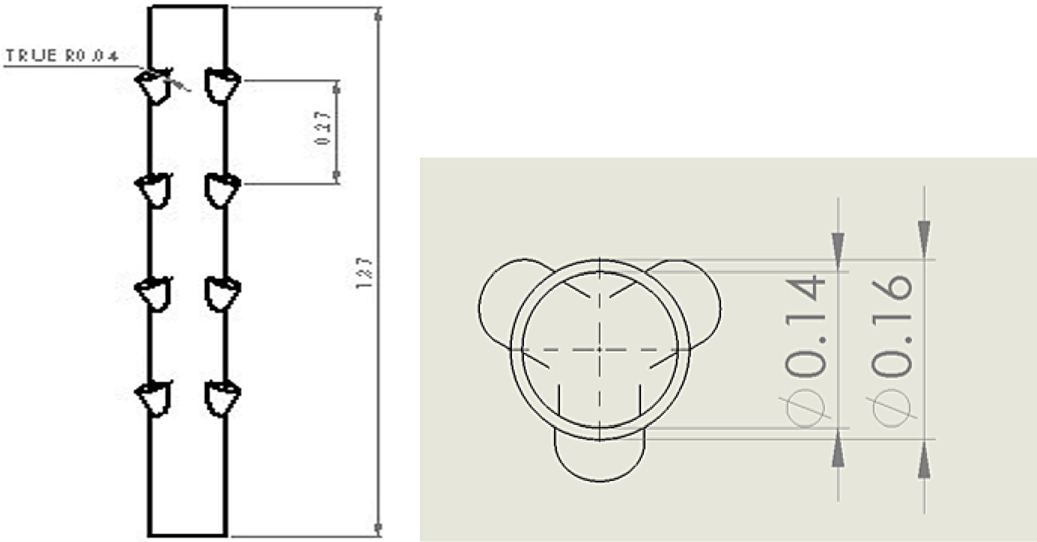


Fig. 2: Hydrostatic load analysis and FOS study



3(a) **3(b)**

Fig. 3: Vertical PVC column (a: front view & b: top view)

For the up-flow of water, a variable flow submersible water pump (SOBO WP-3200) with specified water flow rates of 150, 200 & 250 LPH at low, medium & high settings, respectively is provided in the tank. The pump runs on 220-240V AC (50HZ).

Vertical Plantation Column

This is fabricated using a Ø160 mm PVC pipe with a 4 kg/cm^2 load capacity. The height of the pipe is 1.37 m. This pipe being thermoplastic, the plantation holes are made by heating and reshaping the angle to 20˚ for sufficient support to the plant stem and water retention.[11] The design of the vertical column is shown in Figure 3.

The 76.2 mm neck diameter, 50.8 mm base diameter and 63.5 mm hydroponics cups are used for plantation in this experiment as they provide an adequate volume of ~ 204 CC to have the clay balls as grow media with surface area of nearly about 195 cm^2 required for an average ornamental plant for indoor purposes.[1&12]

In this system, a 12 mm silicon tube is used for carrying water to the top of the vertical pipe, due to its durability and chemically inert properties.[13] The silicon tube is attached to the top cap of the vertical hydroponic plantation pipe.

The rate and direction of water sprinkling are crucial for sufficient nutrient delivery to the plant roots. For this purpose, a rotating quad-channel sprinkler is fabricated using Fiberglass polymer with a 12 mm inlet and 5 mm outlets.

Feeding System

A battery-powered automatic feeder (Resun AF2003) specially calibrated for the vertical aquaponics application is installed, making it a standalone and maintenance-free setup. The feeder capacity is 200 g of 1 mm feed pallets. The automatic feeder is shown in Figure 4.

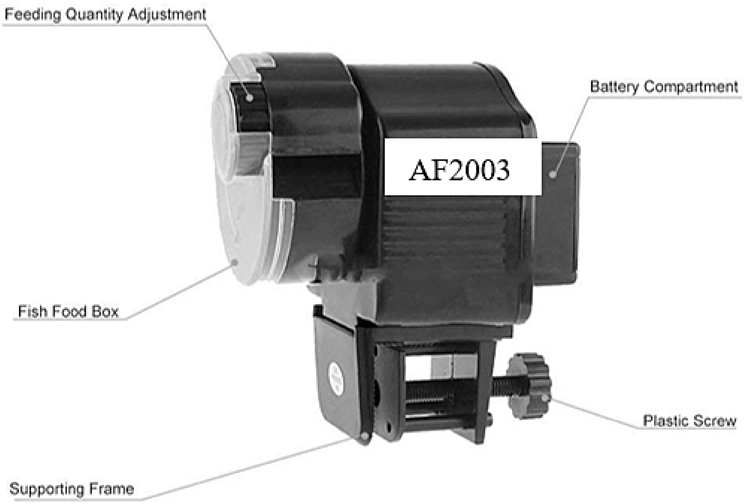


Fig. 4: Automatic feeder (Resun AF2003)

Experimental Plant and Animal

Two species of flowering plant Petunia (*Petunia × hybrida*) and Zinnia (*Zinnia angustifolia*) and Guppy fish (*Poecilia reticulata*) were the experimental specimens.

Experimental Process

The experiment was conducted in triplicate for 30 days in winter months of 2022 at Bhubaneswar, Odisha. Three set-ups were operated simultaneously with three different flow rates 150, 200 and 250

LPH. The fish tank was stocked with 30 numbers of Guppy fish (P. reticulata) of average initial length and weight of 32 ± 6 mm and 0.73 ± 0.08 g respectively. The vertical PVC hydroponics system was planted with 6 numbers of Petunia plant (*Petunia × hybrida*) and 6 numbers of Zinnia plant (*Zinnia angustifolia*) saplings of average initial length and spread of 12.4 ± 3.0 cm and 22 ± 5.6 cm, and 8.5 ± 2.2 cm and 14.3 ± 4.2 cm respectively. The saplings were planted in each plastic net cup with gravels for support to the plant base. During the experiment, plant heights were observed and recorded every week. The flowers produced from each system and/or plants were counted and recored.

Water Quality Analysis

Water from each tank were collected once a week for estimation of physico-chemical parameters. Total Ammoniacal Nitrogen (TAN), Nitrite Nitrogen (NO_2) and Nitrate Nitrogen (NO_3) of the collected samples were analyzed. Dissolved oxygen, pH, and temperature were also monitored. The TAN, NO_2-N and NO_3-N estimations were done in the laboratory with standard procedures.[14]

Flow Rate Calculation

The flow rate at the sprinklers is calculated with the following formula.

$$Q_{sprinkler} = Q_{pump} - \rho gh$$

Where, Q = rate of discharge in LPH
ρ = fluid density (kg/cm_2)
g = acceleration due to gravity (m/s^2)
h = water head (m)

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) V.16 was used to analyse the experimental data. Differences of means were evaluated by one-way ANOVA and Duncan range tests HSD ($p < 0.05$) for the significance.

Results

Flow Rates

The flow rate at the sprinkler is calculated considering the nozzle coefficient of the sprinkler nozzle as 0.8 at 3-speed levels of the submersible pump. The calculated flow rates match the measured values.

Plant Growth and Flowering

The plant growth and spread in relation to flow rate data are tabulated in Table -1(a & b). The plant growth here is a cumulative increase in plant height along with the increase in spread and flower counts in 30 days of experimental period. While comparing the three data sets, the biological productivity in plants at 200 LPH flow rate of the pump (medium setting) gave better plant growth in comparison to other two flow rates, such as 150 and 250 LPH. The highest length & spread for *Zinnia angustifolia* and *Petunia x hybrida* of 37.17±4.27 cm & 39.54±7.45 cm, and 33.43±2.53 cm & 29.58±7.26 cm, respectively were observed at 200 LPH hydrolic loading rate. Therefore, a fixed-flow submersible pump can further reduce the cost of the system.

Table 1(a): Vegatative growth of plants (length) in relation to different flow rates

Sl. No.	Flow rate at pump outlet (LPH)	Flow rate at sprinkler outlet (LPH)	Final Length (cm)					
			Zinnia angustifolia			*Petunia x hybrida*		
			R-1	R-2	R-3	R-1	R-2	R-3
1.	150	138	32.4±5.1	30.7±4.8	33.2±5.1	30.6±4.2	29.7±3.2	31.1±3.5
2.	200	187	36.3±2.4	36.5±6.2	38.7±4.2	33.3±2.6	32.4±2.3	34.6±2.7
3.	250	241	33.6±3.9	35.4±2.7	35.2±6.3	34.2±3.4	34.6±2.6	35.2±3.2

Table 1(b): Vegatative growth of plants (spread) in relation to different flow rates

Sl. No.	Flow rate at pump outlet (LPH)	Flow rate at sprinkler outlet (LPH)	Spread of plant (cm)					
			Zinnia angustifolia			*Petunia x hybrida*		
			R-1	R-2	R-3	R-1	R-2	R-3
1.	150	138	30.03±8.75	27.56±7.41	33.63±8.75	26.14±3.44	23.79±3.18	25.90±6.18
2.	200	187	36.54±7.10	38.13±9.81	44.25±5.44	30.29±2.25	28.43±16.63	30.03±2.91
3.	250	241	31.18±4.80	36.80±2.91	33.63±9.74	32.29±3.33	33.64±2.25	32.91±3.18

Water Quality

During the experiment, water was collected from aquarium, and ammonia, nitrite and nitrate concentrations were estimated. Results (Table 2) revel that ammonia (NH_4+), nitrite (NO_2-) and nitrate (NO_3-) concentrations were significantly lower in tank with flow rate 200 and 250 l/hr, whereas, there was no significant differences ($P>0.05$) in tanks with flow rates of 200 and 250 l/hr (i.e., LPH). The dissolve oxygen (DO) and pH of the water were observed within the range of 4.5-7.8 ppm and 6.0-7.8 during the experiment.

Table 2: Water quality parameters in vertical aquaponics tanks

Water quality parameters (mg/L)	Flow Rate (LPH)		
	150	200	250
NH_3 (TAN)	0.24^b±0.01	0.20^a±0.02	0.19^a±0.01
NO_2	0.40^b±0.02	0.31^a±0.02	0.31^a±0.01
NO_3	3.47^b±0.12	2.80^a±0.17	2.67^a±0.15
DO	4.5-6.5	5.5-7.2	5.5-7.8
pH	6.0-7.1	6.4-7.6	6.6-7.8

Cost of the System

The cost of the vertical aquaponics system was calculated considering the commercial market rates of the components in INR. The cost of the rectangular fish tank, PVC hydroponics pipe, automatic feeder, submersible water pump & tubing with sprinkler were about 3500, 1200, 600, 1000 and 700, respectively. The total cost of one unit became INR 7,000.

Discussion

Although there are not many studies of a similar type for experiments for direct comparison, one study in the relation of gully length to the flow rate of water in a horizontal system suggested that 1.5 L min^{-1} of film flow rate was preferred in a gully of 2 m or less length.[15] However, for the present case, achieving a similar flow rate in a vertical aquaponic pipe and an increased flow rate of 3.12 L min-1 (187.2 LPH) is justifiable and adequate for the application.

The study on the effect of flow rates of the nutrients on hydroponic plants in indoor conditions under a light-emitting diode for 21 days may not be a direct comparison, but the study confirms the hydrolic loading rate of 2-4 L min-1 is best suited for optimum growth of the plants [16 & 17]. The study concluded that for optimum mechanical stimulations for better root growth, an increased flow rate within the mentioned range is preferable. These findings are supportive of the findings of the present study.

In a healthy aquaponic system, the maximum permissible ammonia, nitrite and nitrate levels are 0.5 ppm, 1.0 ppm and 0.5 ppm respectively[18] support effficiency of present vertical aquaponics system. As per the various studies, the water quality parameters like ammonia (NH_4+), nitrite (NO_2-) nitrate (NO_3-), DO and pH values were in permissible range during the experiment.[17&2]

Coclusion

Aquaponics being a sustainable and rapidly evolving agricultural technique, different variations of the aquaponics are being assessed for different aspects of life, like productivity, practility and aesthetic. The later aspect is where majority of households/ hobbyists spend time and money. Vertical aquaponics reduces space utilization and creates an ecosystem for indoor décor as well as the common household spice crops. The experiment helps to derive the optimum setup and parts for efficient and economic vertical aquaponics setup with a cost of approximately INR 7,000. The water quality parameters were within the permissiable limits. Although, there were no significant differences in water quality parameters at 200 and 250 LPH, the flow rate of 200 LPH was found better suited considering the plant growth efficiency in the present study.

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Conflict of Interest

The authors declare no conflict of interest.

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