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Development of A Cascade Aeratror for Small and Medium Fish Farmers in Nigeria

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Abstract:
Aeration devices are designed to create a greater amount of contact between air and water to enhance the transfer of gases and increase oxidation. A cascade aerator is one of gravity aerators and classified as water-into-air aerators and one of the oldest and most common aerators. It consists of a series of steps that the water flows over (similar to a flowing stream). The main features of the cascade aerator were electric motor pump used as prime mover which was of half horse power capacity, and cascade geometry (300 x 100 x 50mm), with eight steps of 1200 mm total lengths made of stainless material and mounted on collector basin made of mild steel and all were supported by angle iron made of galvanized material. Water samples were collected and chemical property (dissolved oxygen) was determined in accordance with American Public Health Association (APHA, 2005). Data were analyzed using descriptive statistics. The result indicated that overall oxygen transfer coefficient, cascade aerator standard aeration efficiency, standard oxygen transfer rate were ranged from 5.15 – 8.21hr^{-1}, 0.11 – 0.21$KgO_2kW^{-1}hr^{-1}$ and 0.04 – 0.08KgO_2hr^{-1} respectively. The cascade aerator improved the water quality by addition of oxygen leading to appreciable increase in the fish stock density which has been a major setback of low-income fish farmer in Nigeria.
Keywords: ***o***xygen dissolved, overall oxygen transfer coefficient, cascade aerator standard aeration efficiency, standard oxygen transfer rate,

1. Introduction

Aeration brings water and air in close contact in order to remove dissolved gases such as carbon (vi) oxide, hydrogen sulphide and volatile organic chemicals. It is often the first process at the treatment plant. All aeration devices (aerators) are designed to create a greater amount of contact between air and water to enhance the transfer of gases and increase oxidation [1 – 5].

Some parameters are used to evaluate and compare between different aeration techniques and operating conditions include Oxygen Transfer Rate (*OTR*), Standard Oxygen Transfer Rate (*SOTR*), and aeration efficiency (η) [5]. The *OTR* is defined as "the quantity of oxygen transferred per unit time to a given volume of water for equivalent conditions such as temperature and chemical composition of water, depth at which air is introduced [6 - 8]. [9] Classified aeration of water into falling water and diffused-air aerators. Falling water aerator depends on dropping water through the process, hence the energy used is the potential energy stored in the form of water head [9], while the diffused-air aerators depend on forcing compressed air or pure oxygen through water using submerged orifices or diffuser [8 – 9]. Other aeration systems are mechanical aerators, in which wastewater is agitated mechanically to boost the solution of air from the atmosphere [8]. The most common aerators used in water treatment are**:**

1. Gravity Aerators**:** In gravity aerators, water is allowed to fall by gravity such that a large area of water is exposed to atmosphere, sometimes aided by turbulence. Cascade aerators and Multi-tray aerators are two examples of this type.
2. Fountain Aerators**:** These are also known as spray aerators with special nozzles to produce a fine spray.

3. Injection or Diffused Aerators**:** It consists of a tank with perforated pipes, tubes or diffuser plates, fixed at the bottom to release fine air bubbles from compressor unit.
4. Mechanical Aerators: Mixing paddles as in flocculation are paddles may be either submerged or at the surface.

A cascade aerator is one of gravity aerators and classified as water-into-air aerators and one of the oldest and most common aerators. It consists of a series of steps that water flows over (similar to a flowing stream). The efficiency of aeration is improved as the fall distance is increased. Cascade aerators are characterized by the strong turbulent mixing, the large residence time and the substantial air bubble entrainment. Air bubble entrainment is caused by turbulence fluctuations acting next to the air-water free surface. It resembles an open channel flow with a series of discrete steps among the invert. In their simplest form cascade aerators consist of a concrete step structure over which water spreads and flow from one level to another in thin films. Experiment conducted by [10] using inclined cascade aerator, the standard oxygen transfer rate (SOTR) value ranged from 0.02 to 0.069 Kg O_2h^{-1} and the standard aerator efficiency (SAE) value ranged from 0.007 to 0.018 $KgO_2KW^{-1}h^{-1}$. The aeration efficiency in cascade aerators can reach up to 90% using 14 steps, at a slope of tan θ = 0.351 and a hydraulic loading rate of 0.009 m_2/sec under nappe flow conditions [11]. [12] highlighted that napple flow as a series of free falling jets with nappe impact on the downstream step with an air cavity forming upstream of each step. The drawback of the cascade aerator is the large space and height needed for the installation [8]. Cascade aerator has been categorized as passive type aerators [9]. It features include thin film aeration and air bubbles entrainment, high exposure time, large installation are and no energy requirement [9, 11 - 14]. Several researchers such as [11 – 13] reported that cascade aeration system at Wena Water works, Nagpur and found that the oxygen transfer increases with; increase in time of exposure at the steps (in other words, with decrease in flow), increase in temperature, other factors remaining constant and total exposed area of the steps. [8,12,13,16], reported that systems with higher number of steps contribute to greater aeration efficiency; furthermore, additional number of steps enhances the aeration as it increases the surface area of fall which results in generation of more air. [13,17–18] reported that cascade aerator is used in the water Treatment process for various reasons:

- To remove the unwanted gases from the water by replacing them with oxygen.
- Increase Oxygen concentration in water.
- Remove CO_2 there by reducing corrosive property.
- Remove taste and odour that are caused by dissolved gases such as H_2S (Hydrogen Sulphide) and CH_4 (Methane) which are removed during aeration.
- Oxidise iron and manganese from their soluble states.
- It is used for denitrification removal of volatile organic components (VOC) such as chlorine and methane

To be successful with any aquatic environment supporting fish, fish culture must know to achieve and maintain a suitable aquatic environment. No one should attempt to be a commercial fish farmer without having aeration devices (aerators) and the knowledge ` if, when and how to use them. DO is probably the single most important environment factor in aquaculture and wastewater treatment. Unfortunately, many fish farmers, researchers, extension specialists, equipment manufacturers and others have a poor understanding of aeration principles. Consequently, they have unrealistic expectations of what benefits aeration can provide. The primary goal of this study was to develop a low cost prototype cascade aerator for fish production using locally available suitable materials for small to medium scale fish ponds in Nigeria.

2. Materials and Methods

2.1 Theoretical Considerations for the design of the cascade aerator Components

The design of this machine was based on design requirements, materials selection and design assumptions as stated in the following subsections.

2.1.1 Material selection

The materials selected for each component part of the machine is presented in Table 1. The isometric view and orthographic projection of the machine are presented in Figures1 and 2, 3, 4, respectively.

The choice of components used for this project is based on the following factors:

- Efficiency of equipment.
- Simplicity of design and cost.
- The major material used for fabricating the essential component parts of the cascade aerator machine were stainless steel and mild steel
- The stainless steel and mild steel were selected because it is easy to weld, machined light, resists oxidation and corrosive attack as it is used inside water.
- Aluminium material reduces weight
- All fasteners are made of stainless steel.

Table 1: Material selection

S/No	Machine Part	Material
1	Cascade	Stainless steel
2	Collector basin	Mild steel
3	Storage tank	Mild steel
4	Electric motor pump	Cast iron
5	Collector basin support	Galvanized steel
6	Delivery pipe	Poly vinyl chloride
7	Electric motor support	Wooden
8	Control valve	Thermoplastic
9	Tap	Stainless steel

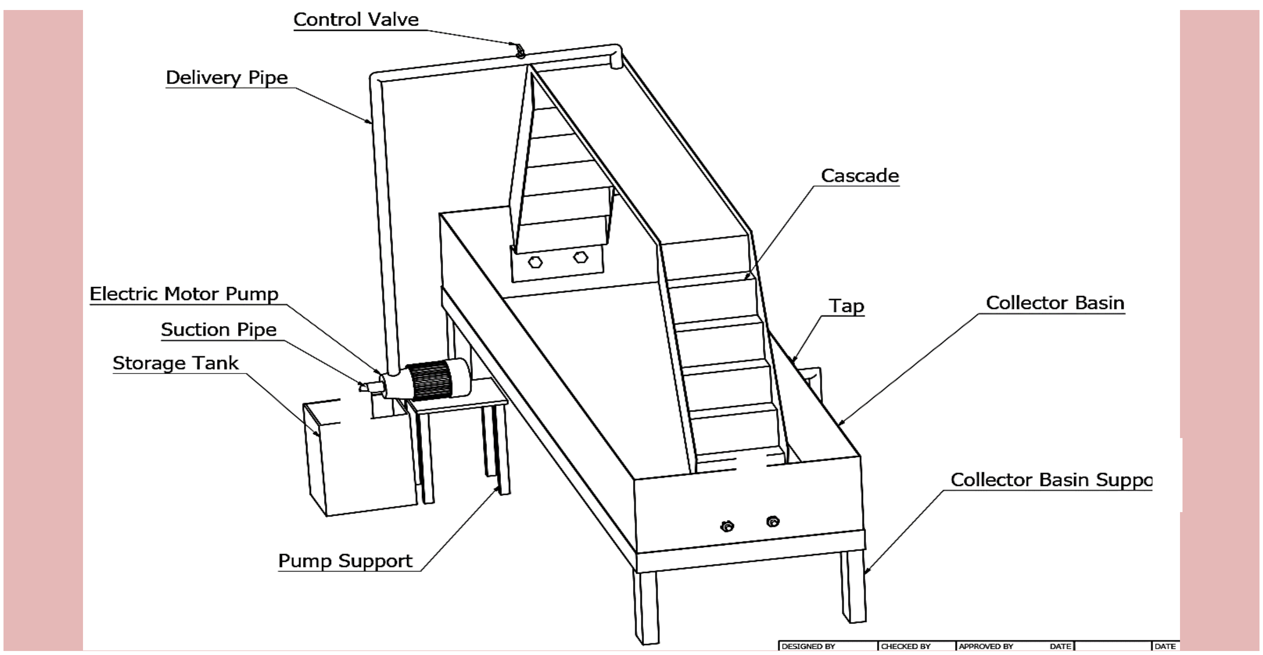

Fig1: Isomeric drawing of Cascade Aerator

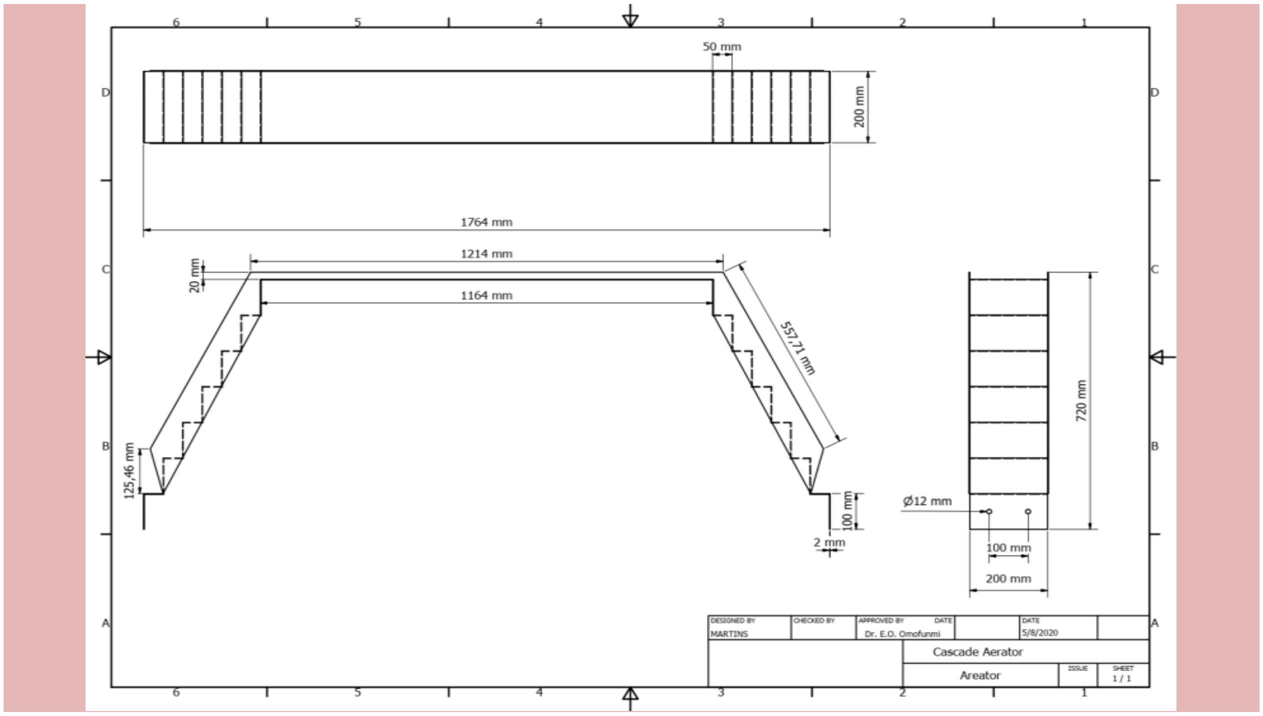

Fig 2: Orthographic view of the Cascade

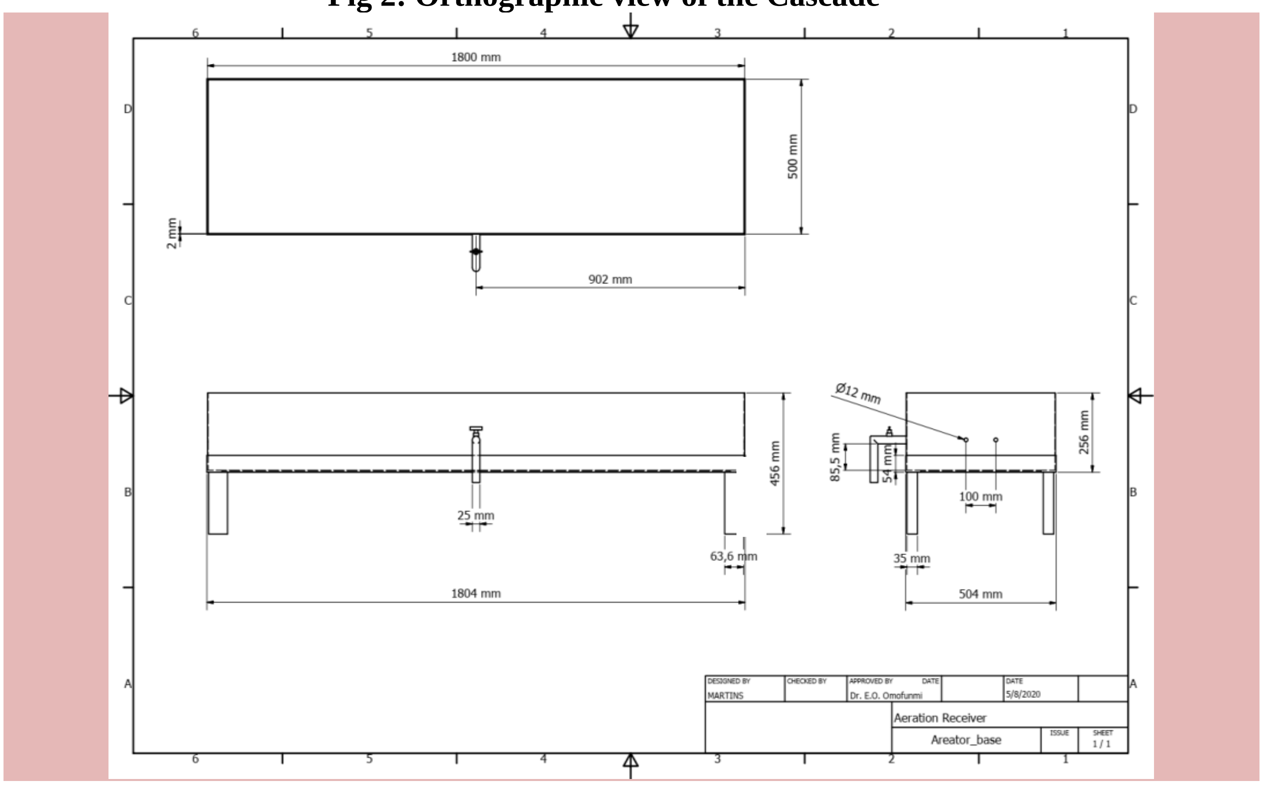

Fig 3: Orthographic view of the Collector Basin

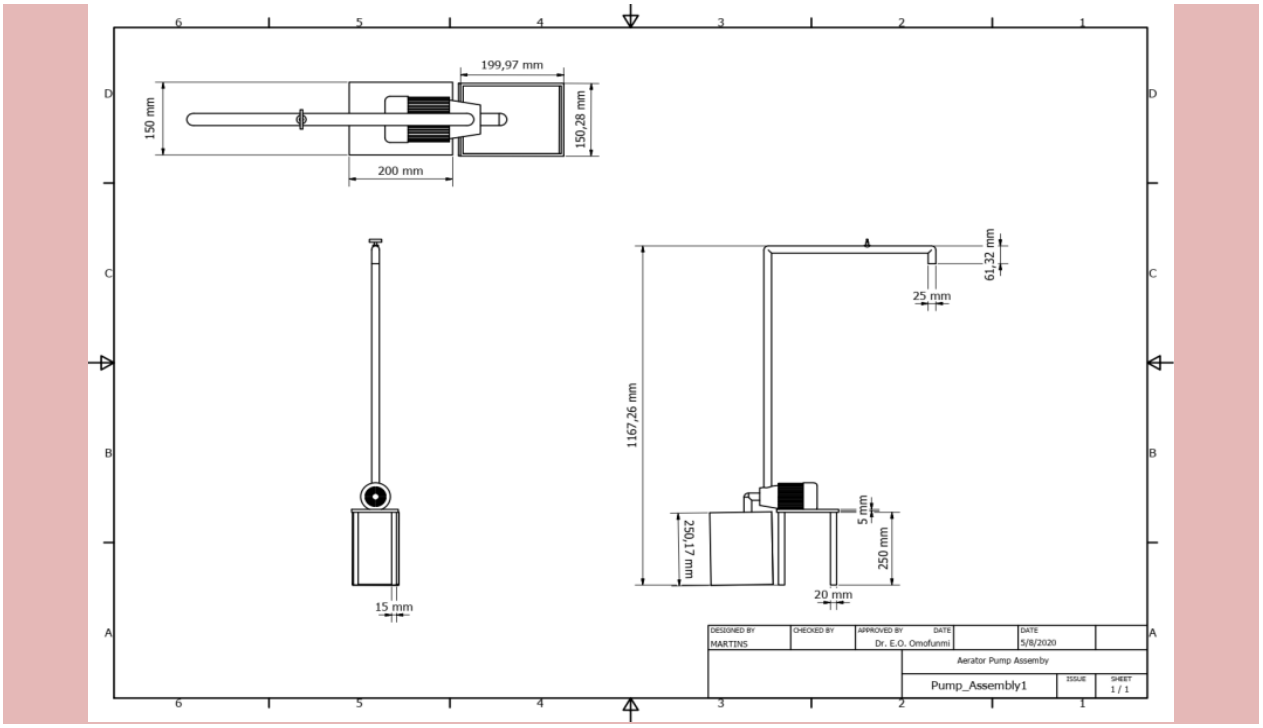

Fig 4: Orthographic view of Pump Assembly

2.2 Description and Operational Principle of the cascade aerator

The keys components of cascade aerator consists storage tank, collector basin, cascade, electric pump, delivery pipe and control valve. Others components are tap, collector basin support and electric pump support

» **The storage tank**

The storage tank serves as reservoir for water storage. It supplies water to collector basin at given volume. It made of mild steel

» **Collector basin**

The collector basin serves duo purposes. It contains volume of water used for the experiments and also received falling water from cascade. It made of mild steel

» **Cascade**

The cascade, placed vertical direction and above collector basin. It consists of eight steps with total length of 1200mm. The Cascade is made of mild steel metal sheet which was bent at a perpendicular angle to get the desired shape. The Cascade is the part of the Cascade Aerator where air is naturally inducted into the cascading water flow.

» **Electric motor pump**

The electric motor pump is of 0.5 hp, provides pressure to the water for moving and lifting through the delivery pipe onto cascade. It is centrifugal type and made of cast iron.

» **Delivery pipe**

The delivery pipe is the discharge-pipe. It is made of polyvinyl chloride of 12.25 mm diameter. It discharges water onto cascade.

» **Control valve**

The control valve serves as water flow rate regulation. It made of thermoplastic

2.3 Design Considerations and Assumptions

In designing this machine, assumed data were used in designed calculation to obtain the machine size, step geometry, surface over flow, rise per step and width of drop. Some of the assumptions are as follows:

(1) The surface over flow (S_{OR}) = 0.01 $m^2/m^3/hr$

(2) The inlet flow rate (I_{FR}) = 3 m3/hr

(3) The rise per step = 150 mm
(4) The Discharge velocity of water = 1.2 m/s
(5) The length of step (L_S) = 300 mm = 0.3 m
(6) The width of drop (W_d) = 50 mm = 0.05 m
(7) Thickness (t) = 5 mm
(8) Number of steps = 8

2.4 Determination of the number of steps (N_{step}) in cascade aerator

$$N_{step} = \frac{Total\ length\ of\ cascade\ (mm)}{Rise\ per\ step} \quad (1)$$

2.4.1 Determination of surface area of cascade aerator (S_{AC})

Surface over flow (S_{OR}) and Inlet flow rate (I_{FR}) are used to determine the surface area of cascade aerator:

$$S_{OR} = 0.01 \frac{m^2}{m^3}\ x\ hr \quad (2)$$

$$I_{FR} = 3\ \frac{m^3}{hr} \quad (3)$$

Surface Area of Cascade (S_{AC})

$$S_{AC} = S_{OR}\ x\ I_{FR} \quad (4)$$

$$S_{AC} = 0.01\ \frac{\mathrm{m}^2}{\mathrm{m}^3}\ \mathrm{x\ hr\ x}\ 3\ \frac{\mathrm{m}^3}{\mathrm{hr}} = 0.03\mathrm{m}^2$$

2.4.2 Design height of Cascade (H_C), and Flow Rate (V_R)

$$H_C = width\ of\ drop\ x\ 2 \quad (5)$$

$$H_C = 2 \text{ x } 50 = 100 \text{ mm}$$

$$V_R = area\ x\ speed \quad (6)$$

$$V_R = 0.3 \text{ x } 1.2 = 0.36\ \frac{\mathrm{m}^3}{\mathrm{s}}$$

2.4.3 Total length of cascade (T_{LC})

$$D_L = L_S\ x\ H_C \quad (7)$$

$$D_L = 300\ (2 \text{ x } 50) = 400 \text{ mm}$$

Where,
D_L = Design length, mm
L_S = Length of cascade, mm
H_C = Design height of cascade, mm

$$T_{LC} = D_L + W_d\ x\ 2 \quad (8)$$

T_{LC} = Total length of cascade, mm
W_{drop} = Width of drop, mm

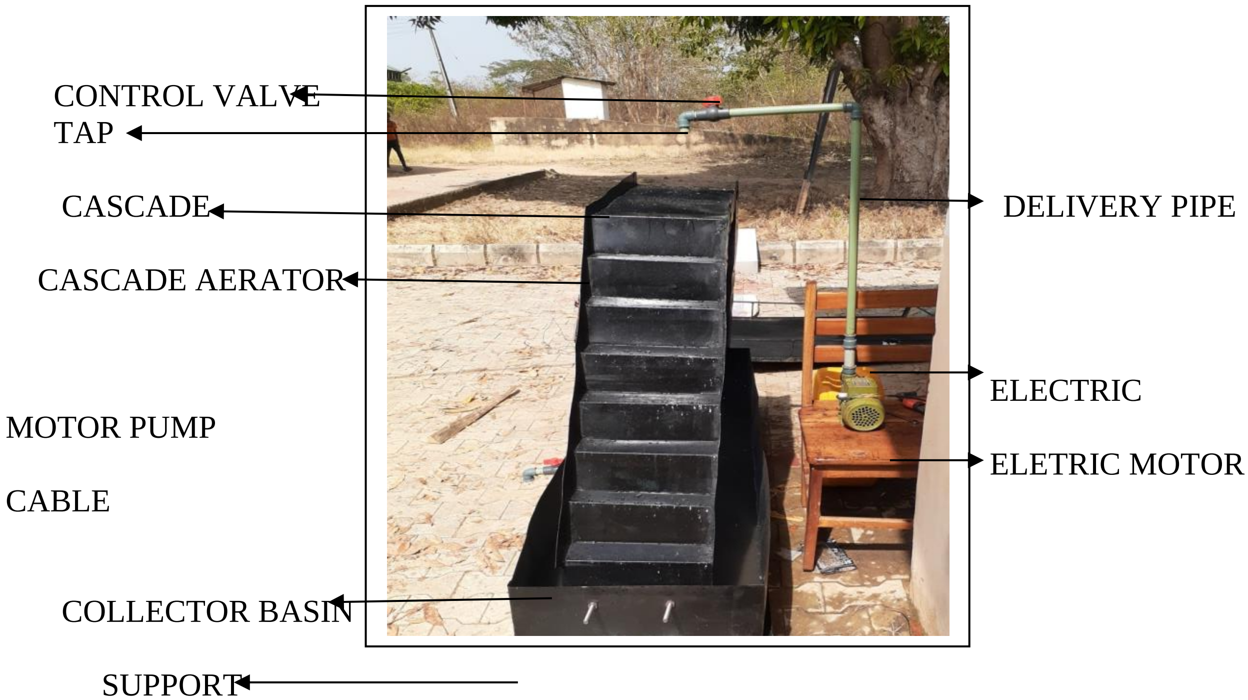

Plate 1: Cascade Aerator

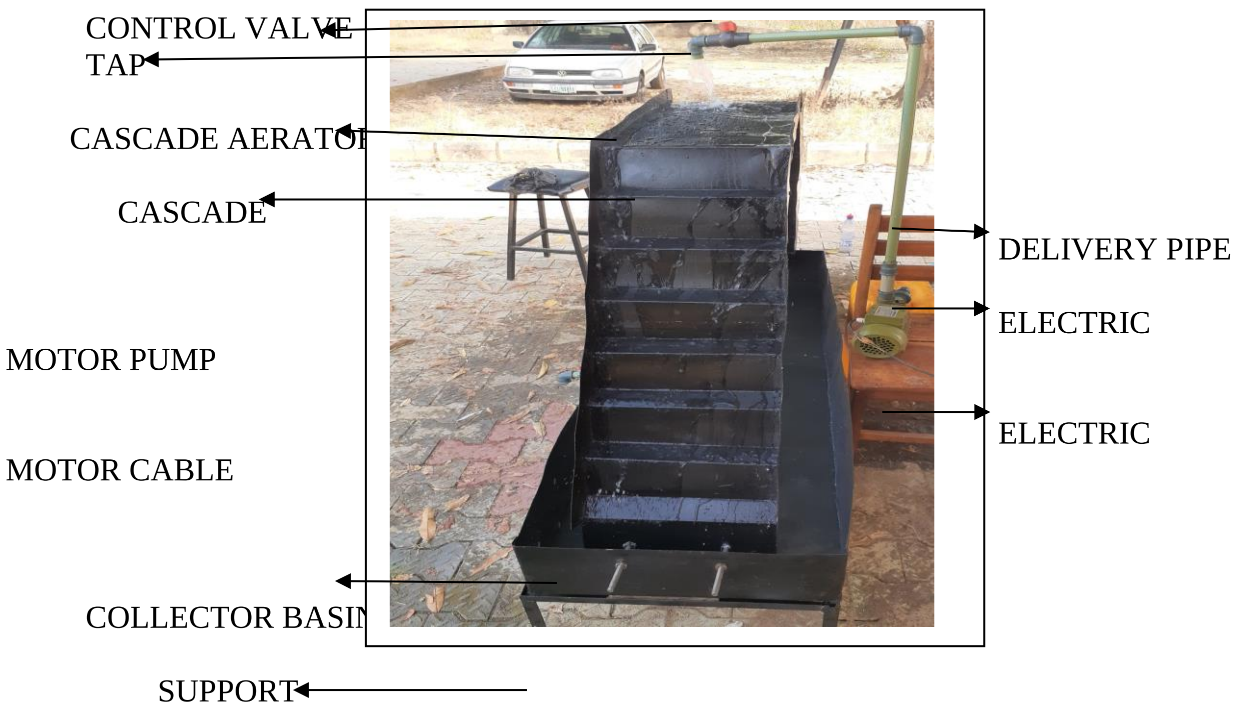

Fig. 4: Mounted Cascade Aerator for Operation

2.5 Experimentation and Sample collection

The aerator performance was conducted using Non-steady-state aeration test. The test basin was filled to the appropriate depth wih water from a tap. Enough Cobalt Chloride and Sodium Sulphite were provided in the test basin and mixed by running the aerator. The masses of Cobalt Chloride and Sodium Sulphite used per cubic metres are presented in **Table 2**. The operated cascade aerator had shown in (**Fig. 3**). Oxygen transfer tests were conducted in basin. After maintain DO between 0.0 - 0.1 mg/l for about 5 minutes, the cascade aerator operated and dissolved oxygen (C_m) was taken at five minutes interval until DO increased from 0% saturation to at least 90% saturation. This prototype cascade aerator operation performance was powered throughout by 0.375 kW (0.5 hp) electric motor pump and volume range of 0.08 m^3 to 0.15 m^3. Water samples were collected at 5 minutes intervals for each runs. 250 ml glass bottles were used for the sampling and the sampled were analyzed for dissolved oxygen (DO). Water temperature was determined by thermometer

Table 2: The quality of Cobalt Chloride and Sodium Sulphate used per cubic Metres for the deoxygenated volume of water

Volume of water (m^2)	Mass of Cobalt Chloride (g)	Mass of Sodium Sulphite (g)
0.08	1.6	160
0.10	2.0	200
0.11	2.2	220
0.13	2.6	260
0.15	3.0	300

2.6 Determination of chemical property of water sample

Dissolved oxygen (DO): The dissolved oxygen (DO) was determined by Winker's method. Water sample for DO were collected at each location in 100 ml DO sample bottle without agitating. The stopper was carefully removed. 1ml each of sodium iodide (Nal) solution and magnesium Sulphate ($MgSO_4$) solution were added with aid of 1ml pipette, the stopper was replaced and the content was thoroughly mixed, 2.0 ml of concentrated Sulphuric acid (H2SO4) was added mixture, 50 ml of the solution was titrated with 0.025N of Sodium thiosulphate ($Na_2S_2O_3$) with starch solution as indicator of the colourless end point. The dissolve oxygen (mg/l) is expressed as follows: DO (mg/l) = ml of 0.025(N) $Na_2S_2O_3$ used x 4 (APHA, 2005).

2.7 Data Analysis.

Chemical property of water sample was determined in accordance with the American Public Health Association Standards [19]. Data were analyzed using descriptive statistics.

The following equations were used for the determination of the oxygen transfer rate (K_L^a), standard oxygen transfer rate (SOTR) and the standard aeration efficiency (SAE).

$$(K_L^a)^{20} = K_L^a \; x \; 1.024^{20-T} \tag{9}$$

$$SORT = K_L^a T \left(\frac{KO_2}{M^2}\right) 1 \; x \; 10^{-3} \frac{Kg}{g}) \tag{10}$$

$$SAE = \frac{SORT}{P} \tag{11}$$

Where,

K_L^a = Oxygen transfer rate, hr^{-1}

T = Temperature, ^0C

P = Power, kW

3. Results And Discussion

3.1 Length of cascade aerator

The length of cascade aerator is presented in Table 3.

Table 3: Length of cascade aerator at each step

Number of step	Dimension (mm)	Total length (mm)
1	400 + (50 x 2)	500
2	500 + (50 x 2)	600
3	600 + (50 x 2)	700
4	700 + (50 x 2)	800
5	800 + (50 x 2)	900
6	900 + (50 x 2)	1000
7	1000 + (50 x 2)	1100
8	1100 + (50 x 2)	1200

3.2 Performance of the Cascade Aerator

The component parts and dimensions of the machine are presented in Table 4. Locally developed prototype of cascade aerator is presented in Plate 1. The predictive equations indicated that the oxygen transfer rate (OTR), standard oxygen transfer rate (SOTR) and standard aerator efficiency (SAE) was found to decrease with increase in the volume of water. The standard oxygen transfer rate (SOTR) and standard aerator efficiency of developed cascade aerator (SAE) ranged from 0.04 – 0.08 KgO_2hr^{-1} and 0.11 – 0.21 $KgkW^{-1}hr^{-1}$ respectively. The results indicated that the effectiveness of the designed prototype machine depends on the volume of water, number and width of cascade.

The summary of the results of the developed cascade aerator is presented in Table 5. Result of [10] using inclined cascade aerator indicated that standard oxygen transfer rate (SOTR) and standard aerator efficiency (SAE) ranged 0.02 - 0.069 Kg O_2hr^{-1} and 0.007 to 0.018 $KgO_2kW^{-1}hr^{-1}$.respectively. These differences may be due to step geometry (height and length) of cascade, numbers of steps, flow rate, quality of water and retention time

Table 4: The component parts and dimensions of the machine

S/N	Component	Dimension
1	Height of cascade	100 mm
2	Length of cascade	300 mm
3	Total length of cascade	1200 mm
4	Flow rate	0.36 m^3/s
5	Power of electric pump	0.5 hp (375 W)
6	Number of steps	8
7	Standard oxygen transfer rate (SOTR)	0.04 – 0.08 KgO_2hr^{-1}
8	Standard aerator efficiency (SAE)	0.11 – 0.21 $KgO_2kW^{-1}hr^{-1}$

Table 5: Summary of Oxygen transfer coefficient (K_L^a), Standard Oxygen Transfer Rate (SOTR) and Standard Aerator Efficiency (SAE) for the Cascade Aerator

Volume of Water (m^3)	Oxygen Transfer Coefficient (K_L^a)hr^{-1}	SORT (KgO_2hr^{-1})	SAE ($KgO_2kW^{-1}hr^{-1}$)
0.08	8.21	0.08	0.21
0.10	7.23	0.07	0.19
0.11	6.23	0.06	0.16
0.13	5.74	0.05	0.13
0.15	5.15	0.04	0.11

4. Conclusion

The prototype of cascade aerator was developed with local materials and powered by a 0.5 hp electric motor pump which was operated at a speed of 1.2 m/s. It has eight steps with total length of 1200mm. The dissolved oxygen was used for the assessment of efficiency of the machine. The results indicated that:

− The effectiveness of the machine depends on the number and width of cascade

− The efficiency of the machine can be improved upon by increasing the step geometry and reduce the flow rate

− It improves dissolved oxygen contents of water
− It can be used for fish stock density increments
− It can be used for treatment of fish effluent with high dissolved organic matter
− It can be used for H_2S, CO_2, NH_3 and NO_2 reduction
− The effectiveness depends on concentration of organic matter
− It cannot be used for treatment of high concentration wastewater
− The variation of flow rate should be assessed.

References

[1] Tucker C. S. and Robinson E. H., "Channel Catfish Farming Handbook" New York: Nosttand Reinhold. pp. 686 – 692, 1990

[2] Boyd C. E., "Aquaculture and water pollution" Decision support system for water resources management. American Association, Middleburg, Virginia. USA. pp. 153 – 157, 2001

[3] Boyd C. E., "Guidelines for aquaculture effluent management at the farm level" Aquaculture, 226:101 – 112, 2003

[4] Tucker C. S., "Pond Aeration: Southern Regional Aquaculture Center Fact Sheet. pp. 370 - 374, 2005

[5] Omofunmi O. E., "Development of a Paddle Wheel Aerator for Catfish Effluent control and its effects on Environment in Lagos State: Nigeria. Unpublished Ph.D. Thesis, Federal University of Agriculture, Abeokuta, Nigeria. pp. 121 – 129, 2014.

[6] Mueller J.A., Boyle W.C. and Popel H. J., "Aeration principles and practice" Boca Raton: CRC Press. pp. 32 1 – 319, 2002

[7] ASCE., "Measurement of Oxygen Transfer in Clean Water" ASCE Standard, ASCE/EWRI. pp. 1 – 32, 2007

[8] Tchobanoglous G., "Wastewater engineering" treatment and reuse, McGraw-Hill. pp. 398 – 406, 2004

[9] Scott G. R., Aeration of water: Revision of "Water Quality and Treatment" Chapter 6. (American Water Works Association), 47 (9): 873 – 885, 1955

[10] Doley H., Kumar A., Ghosh M. and Das A., "Performance evaluation of inclined cascade aerator" Journals of Basic and Applied Engineering Research. 2(11):941 – 946, 2015

[11] Moulick S., "Aeration characteristics of a rectangular stepped cascade system" Water Science & Technology, 61(2): 415 - 416, 2010

[12] Baylar A., Bagatur T. and Emiroglu M.E., "Prediction of oxygen content of nappe" transition and skimming flow regimes in stepped-channel chutes. Journal of Environmental Engineering and Science. 6(2): 201 – 208, 2007

[13] Toombes L. A. and Chanson H., "Air-Water Mass Transfer on a stepped Waterway" Journal of Environmental Engineering, 131(10):1377 – 1386, 2005

[14] Sabry T. I., Hamdy W. and Alsaleem S. S., "Application of Different Methods of Natural" Aeration of Wastewater and their Influence on the treatment Efficiency of the Biological Filtration. Journal of American Science. 6(12):944 – 952, 2010

[15] Thakre C. S. and Hedaoo M. N., "Rational approach for design of cascade aerator, proceedings of the 26th WEDC Conference on Water" Sanitation and Hygiene: Challenges of the Millennium, November 2000, Dhaka Bangledesh. pp. 248 – 250, 2000

[16] Howe K. J., Hand D. W., Crittenden J. C., Trussel R. R. and Technobanoglous G., "Principles of Water Treatment" 1st Edition. Publishing by Wiley, U.S. pp. 594 – 606, 2012

[17] Baylar A., Unsal M. and Ozkan F., "Hydraulic Structures in Water Aeration Processes" Water, Air, Soil pollution. 210(1 – 4): 87 – 100, 2009

[18] Rathinakumar V., Dhinakaran G. and Suribabu C. R., "Assessment of Aeration Capacity of Stepped Cascade System for Selected Geometry Journal of Environmental Engineering and Science, 6(1):254 – 262, 2014

[19] American Public Health Association (APHA), "Standard Methods for the Examination of Water and Wastewater" 16th and 17th Editions. Washington, DC; American Water Works Association, Water Control Federation, 2005