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Development Of A Paddle Wheel Aerator For Small And Medium Fish Farmers InNigeria

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Abstract:*Pond aeration systems were developed to sustain large quantities of fish and biomass materials. In this study the importance and functions of aeration were examined and prototype paddle wheel aerator was developed. The main features of the paddle wheel aerator wereelectric motor used as prime mover which was of one horse power capacity, Paddle hubs with six paddles all mounted on a shaft made of stainless steel and brass materials. Aeration experiment was conducted in water basin made up of plastic. Paddle-wheel aerator performance evaluation was conducted using unsteady state test.Physico-chemicalproperties of water sampled from the tested ponds were determined in accordance with the American Public Health Association standards (APHA, 2005). Performance test carriedout showed that the overall oxygen transfer co-efficient (K_La) was observed to be as high as 8.19 $hr^{-1}$and standard oxygen transfer rate (SOTR) and standard aerator efficiency (SAE) ranged from 1.1 – 1.2 kgO_2hr^{-1} and 1.1 – 1.3 kg O_2KW^{-1} hr^{-1}respectively. The paddle wheel 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:*Oxygen dissolved, overall oxygen transfer coefficient, paddle wheel aeratorstandard aeration efficiency, standard oxygen transfer rate, water basin*

I. Introduction

During the past decade, pond aeration systems have been developed which will sustain large quantities of fish and invertebrate biomass. These aeration systems are modifications of standard wastewater aeration equipment. Paddle-wheel aerator is surface aeration system which can be vertical shaft or horizontal shaft that producing a large air-water interface the transfer of oxygen from atmosphere is enhanced.The importance and functions of aeration process is hereby highlighted by some investigators like Boyd (2001`, 2003) ;Tucker 2005; Tucker and Robinson, 1990) include:

- it reduces the concentrations of ammonia, nitrites and carbon (iv) oxide
- it increases pH level of pond water.
- it increases the carrying capacity of an aquaculture system.
- it reduces fish mortality.
- it enhances fish reproduction systems
- it reduces level of salinity especially during time of low rainfall
- it increases pond productivity.
- it increases fish growth.
- it regulates water temperature especially as this can affect dissolved oxygen (DO) of aquatic
- it is used to control thermal stratification and
- it prevent eutrophication in fish ponds

Types of aerators are:

1) Gravity Aerator: 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
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: These may be paddles or spiral types, it increases interfacial area by spraying water droplet into the air. Paddles may be either submerged or at the surface.

Out of these aerators, the mechanical surface aerators are widely used because they offer better efficiency as well as convenience in operation and maintenance. Oxygen transfer rate from gas to liquid phase for paddle-wheel aerator is functions of variables such as speed, mixing intensity and turbulence, geometrical variables such as size and number of paddles, arrangement of the paddles, depth of flow and physicochemical properties of the liquid. American public health association(APHA, 2005) states that for proper mixing of dissolved oxygen (D0) throughout the water volume, the power-to-volume ratio should lie within 0.01 – 0.04 kW/ m^3.Boyd (1998) highlighted that aeration –performance testing has been found important in selecting design features to provide cost-effective yet efficient aquaculture pond aerators. Paddlewheel aerators and propeller-aspirator-pumps are probably most widely used in fish cultures. Boyd (1998) reported that paddlewheel aerators constructed according to, or similar to, a design by Ahmad and Boyd (1988) had the highest standard oxygen transfer rate (SOTR) and standard aerator efficiency (SAE) values. The values for SOTR ranged from 17.4 to 23.2 Kg O_2 h^{-1} .and values for SAE (based on (shaft power) ranged from 2.6 to 3.0 Kg O_2 $W^{-1}h^{-1.}$ Aeration performance tests in tanks (Boyd and Ahmad, 1997) indicate that paddle wheel aerators were more efficient in transferring oxygen and circulating water than other types of aerators commonly used in aquaculture. Rappaport et al. (1996) made pond tests of several aeration systems (paddle wheels, aspirator, vertical pump, and diffused-air), found that paddle wheel aerators were much more efficient than the other types. Ahmad and Boyd (1988) developed a highly efficient design for 3- 10-hp paddle wheel aerators. This design has been used by several companies to manufacture 3-, 5-, and 10-hp aerators and many aerators of similar design are used in commercial channel catfish ponds in the Southeastern United States. Boyd and Ahmad (1997) Moore and Boyd, (1992)highlighted that aquacultural research is often conducted in small ponds of 500-5000 m^2 in area and small ponds are also used in some types of commercial aquaculture. Aerators of 0.25-2hp are often used in smaller ponds. Small paddle wheel aerators (1 and 2 hp) are made in Taiwan and sold Worldwide for use in small ponds. These units are widely used because they are available and relatively inexpensive, but they are not very durable and their oxygen-transfer efficiency is low (Boyd and Ahmad, 1987).They often create excessive water turbulence and turbidity in earthen ponds less than 1000-1500 m^2 in area. Attempts to produce small, highly efficient paddle wheel aerators using design features provided by Ahmad and Boyd (1988) for larger aerators have not been very useful. Electric paddle wheel aerators are widely used in pond aquaculture.

Paddlewheel are commonly used in fish culture and is one of the major capital cost item in the farm. The primary goal of this study wastodeveloplow cost prototype paddle wheel aerator for catfish production using locally availablesuitable materials for small to medium scale fish ponds in Nigerian.

II. Materials And Methods

2.1Material Selection

The materials selected were as presented in Table 1. Isometricand orthographic projections of apaddle wheel aerator are presented in Figures 1 and 2 respectively

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

(1) Simplicity of design,
(2) Cost -effectiveness
(3) The major material used for the fabrication of essential components of this paddle wheel aerator machine was stainless steel, because of its ability to be easily welded, machined, resists oxidation and corrosive attack as it being used inside water and readily available.

2.2 Design requirements

The paddle wheel aerator was designed to meet the following requirements:

(1) Low cost
(2) Use locally-available materials
(3) Ease of fabrication
(4) Portability and ease of assemble / disassembly
(5) Repeatability and ease of operation
(6) Low maintenance requirements

2.3Design equations and assumptions

Coefficient of friction existing between paddle wheel and water surface, k

$k = \tan^{-1}\frac{(sin\alpha cot\varphi\ )}{90-\varphi}$ --------------------------------- (1) (John, 1995)

$\varphi = \alpha + \frac{\emptyset}{2}$ -- (2) (John, 1995)

Where:

ω = Angle of splashing of rotate paddle with horizontal
Φ = Splashing angle make with horizontal
α= Angle of splashing resistance of rotate paddle with depth

The calculation for the Vertical Water force per unit depth (PV)

$PV = \gamma Z^2 N_\gamma + CZN_C + C_\alpha Z N_\alpha + gZN_g$-------------------------- (3) (John, 1995)

The Sideways Water Force per Unit Width PS

$PS = \left(\frac{C_\alpha Z N_{sc}}{2} + \gamma\left(\frac{Z}{2}\right)^2 N_{s\alpha} + \left(\frac{N_g}{\gamma}\right)^2 N_{s\alpha}\right)k$-------------------- (4) (John, 1995)

Where:
Nr, Nc, Ng and Nα are dimensionless (Resce factors)
Y = Water unit weight (N/m^2)
Z = Depth of blade (m)

The value for the resistance force P

$P = P_s + P_v cos\beta$---(5) (John, 1995)

Where: β = Angle of water / interface between paddle edge and water

The draught per unit width D_F

$D_F = PVsin(\alpha + \beta) + PSsin\alpha + C_\alpha \gamma cos\alpha$ --------------------- (6) (John, 1995)

The Vertical Force per Unit Width F_V

$F_V = PVcos(\alpha + \beta) + PScos\alpha + C_\alpha N$----------------------------(7) (John, 1995)

The Total Vertical Force per Unit Width V_T

$V_T = F_V . b$ --- (8) (John, 1995)

Bending moment for the machine M

$M = \frac{2}{3} V_T cos\alpha \times h$--- (9) (John, 1995)

$\delta_x = \frac{Ml}{I}$ --- ------(10) (Khurmi and Gupta, 2011)

$ba = b \times factorofsafety$---(11) (John, 1995)

The total power requirement to rotate the paddle wheel

$P = P_T b 2\pi r n$ -- (12) (John, 1995)

Selection of the dimension of spur gear and pinion and determination of shaft diameter

Gear and pinion were selected anddetermination of shaft diameters for both electric motor and paddle-wheel using Khurmi and Gupta, 2011 equations

2.4Aeration Test

The aerator performance was conducted using Non-steady-state aeration test. The test basin was filled to the appropriate depth with water from a tap. Enough Cobalt Chloride and Sodium Sulphitewere provided in the test basin and mixed by running the aerator. The masses of Cobalt Chloride and Sodium Sulphite used per cubicmetres are presented in Table 1. The aerator shaft was 105cm above the floor of the aerator test basin (plate 2). Oxygen-transfer tests were conducted in basin. After maintain DO between 0.0 – 0.1 mg .L for about 5 minutes,the paddle wheel aerator was run and dissolved oxygen(C_m) was taken at two minutes interval until DO increased from 0% saturation to at least 90% saturation. This prototype paddle wheel aerator operation performance was powered throughout by 0.75KW (1hp) electric motor at 881rpm at various depth range from 16cm to 30 cm and volume range of $1m^3$ to $8m^3$ at $1m^3$ interval this was to determine the optimum uniformity effectiveness of the machine in transmitting dissolved oxygen in the water over two minutes interval. The DO concentrations at saturation (Cs) for water in the aerator test basin were computed for the ambient water temperature and barometric pressure at 15cm depth with the initial dissolved oxygen (C_s) 6.65mg/ l and water temperature at 28.8^0C and barometric pressure at 758.8mmHg using a polargraphic DO meter, thermometer and aneroid barometer respectively. Apolargraphic DO meter was used to measure DO concentrations (DO_m) at three places in the basin for at ten equal time intervals while the aerator raised the DO concentration from less than 10% of saturation to about 90% of saturation. The mass oxygen-transfer coefficient at the test temperature (K_La) was calculated as the slope of the regression line for the natural logarithm of the DO deficit ($C_s – C_m$) relative to time between 10% and 70% saturation. The K_La was determined for each sampling point. The K_La was corrected to 20^0C by

$(K_La)_{20} = K_La \times 1.024^{20-T}$ (13)

The standard oxygen transfer rate (SOTR) and the standard aeration efficiency (SAE) were used to determined the aerator performance:

SORT = $K_LaT(kO_2) /m^3(1x10^{-3}kg/g)$(14)

SAE = SORT /P (15)

Where:

K_{La}= Oxygen transfer coefficient

T =Temperature (^oC)

P = Power (kW)

Table 1: Material selection

S/ N	Machine part	Material
1	Base	Iron
2	Paddle wheel shaft	stainless steel
3	Paddle	Stainless steel
4	Shaft	Brass
5	Control box	Brass
6	Paddle hub	Stainless steel
7	Motor	Brass
8	Gear box	Brass
9	Motor support	Iron

III. Results And Discussion

Prototype of paddle wheel 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) were found to decrease with increase in the volume of water. The result agreed with Boyd (1998) that the standard oxygen transfer rate (SOTR) and standard aerator efficiency (SAE) of the paddle wheel aerators were inversely proportional to the volume of water, other parameters remain constant. This finding differs slightly from evaluations made by other investigators. Result of Boyd (1990) evaluates indicated that standard oxygen transfer rate and standard aerator efficiency for twenty four types of the paddle wheel aerators ranged from 1.9 – 8.5 (kg O_2 hr^{-1}) and 1.2 – 5.2 (kg O_2KW^{-1} hr^{-1}) respectively. Evaluation of Ahmad and Boyd (1997) and Moore and Boyd, (1992)indicated that standard oxygen transfer rate and standard aerator efficiency for six paddle wheel aerators ranged from 5.2 – 18.5 (kg O_2 hr^{-1}) and 2.6 – 3.0 (kg O_2KW^{-1} hr^{-1}) respectively. These differences may be due to different size of paddle, numbers of paddle, arrangement of the paddle on the hub, speed of the paddle wheel aerator, the depth of operation, types of prime mover, power used, geometrical of basin and physicochemical properties of water. The effectiveness level, the range and restrictive feature was presented in Table 3. The results indicated that the effectiveness of the designed prototype machine depends on the volume of water and it is occurred at $2m^3$ or less volume of water, the prototype machine developed provided adequate supply and uniform and equal distribution and mixing of dissolved oxygen in the system (see from Tables 2and 3) $2m^3$ to $5m^3$ supplied and provide mixing of dissolved oxygen at non-uniformity of dissolved oxygen in entire volume. At pond water volume above $5m^{3,}$ dead zones and oxygen stratification occurred. From this result of the developed prototype performance evaluation and analysis, machinery extrapolation design development can be carried out for pond water volume in multiples of $2m^3$ pond water.

Table 2: Summary of Oxygen transfer coefficient, Standard Oxygen Transfer Rate (SOTR) and Standard Aeration Efficiency (SAE) for the Paddle wheel aerator

Volume of Water (m^3)	Gradient	Oxygen transfer CoefficientK_La (hr^{-1})	SOT R (kgO_2hr^{-1})	SAE ($kgO_2KW^{-1}hr^{-1}$)
1	0.16	8.19	1.30	1.34
2	0.14	7.20	1.29	1.30
3	0.13	6.65	1.25	1.27
4	0.11	5.56	1.21	1.23
5	0.09	4.65	1.19	1.19

6	0.08	4.18	1.11	1.17
7	0.07	3.52	1.10	1.15
8	0.06	3.08	1.09	1.13

IV. Conclusions

A pilot scale**,** low – cost, portable prototype indicate it capacity paddle wheel aerator was developed locally. The machine was pumped in circle and there was dissolved oxygen gradient in basin. More engineering and planning are required to use the machine, such as designing the structural supports, baffles and tankwalls/bottom. Long delivery time is common. The machine is effective and efficient at water volume equal to or less than $2m^3$pond water. This device is recommended for modification to perfect it functions and for scaling up for the benefit of the large scale fish industry at large

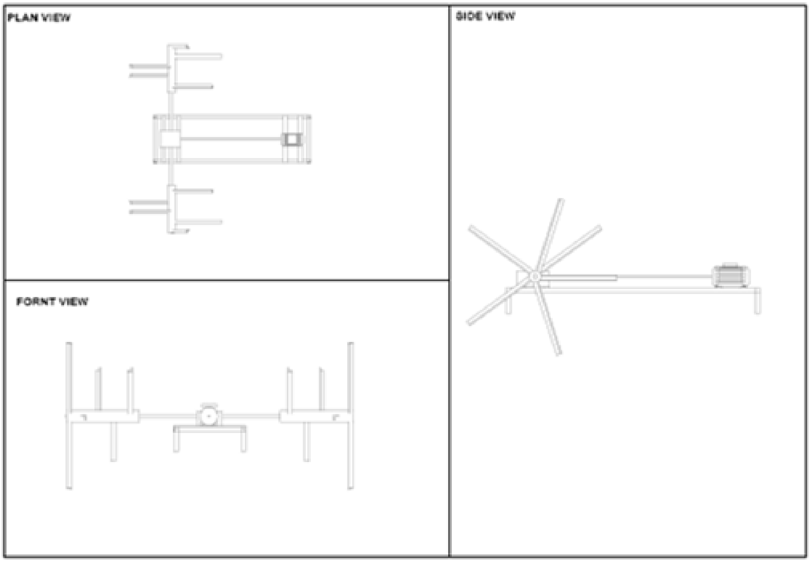

Fig 2: Orthographic drawing of paddle wheel aerator

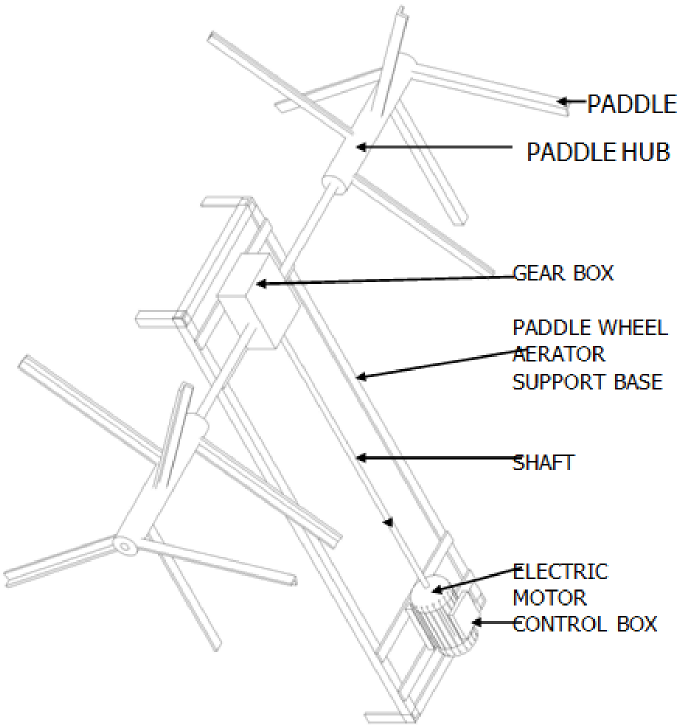

Fig.1: Isometric drawing of paddle wheel aerator

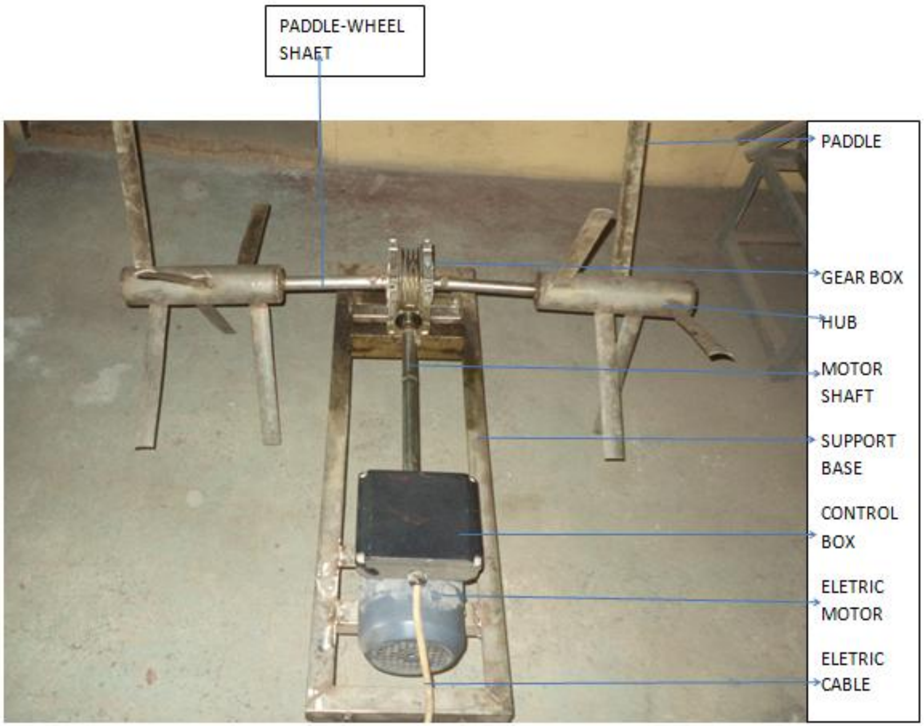

Plate 1: Paddle-Wheel aerator

Plate 2: Mounted Paddle Wheel Aerator for Operation

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