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Design Characteristics of Submersible Aerator

Jayraj P[1], Subha M. Roy[1*], C. K. Mukherjee[1] and B. C. Mal[2]

[1] Indian Institute of Technology Kharagpur West, Agricultural and Food Engineering Department Bengal, India, Pin -721 302

[2] Vice Chancellor, JIS University, Agarpara, Kolkata, West Bengal, India, Pin - 700 109

Phone:

Email: subhamanash@gmail.com, smroy.agfe@iitkgp.ac.in

Abstract

Aeration experiments were conducted on original and modified submersible aerator to evaluate its performance and to optimize the aeration efficiency. The angular position of the propeller (α) and submergence depth of the propeller (d) were varied to study their effects on standard aeration efficiency (SAE). Pre-performance evaluation of the original design without having a provision to vary α and d was done and resulted in an SAE of 0.320 kg O_2/ kWh. The aerator was modified to have a provision to change α and d of the aerator. To evaluate the optimum α, experiments were conducted at different α: 0º, 15º, 30º, 45º, 60º, 75º, keeping the rotational speed (N) = 2900 rpm and d = 450 mm as constants. The optimized α was 75º. In the same way to optimize d, experiments were conducted at different d: 300, 350, 400, 450, 500, 550, and 600 mm, keeping N = 2900 rpm and α = 75º as constants. The optimized d was 350 mm. Finally the optimized value of SAE of 0.616 kg O_2/ kWh was achieved at α = 75º and d = 350 mm. The percentage increase in `efficiency after modification was found to be 92.50 %.

Keywords: Submersible aerator, aeration efficiency, angular position of the propellers, submergence depth of the propeller

Introduction

Increased need for fish coupled with decreased fish production from natural water bodies has necessitated boosting of fish production worldwide. India has huge potential for growth in the field of fresh water and brackish water aquaculture through extensive and semi intensive cultivation techniques. The qualities of water use for aquaculture mainly determine the success and failure of culture practice. Fishes or other culture species totally depend upon water to breath, feed, grow, excrete etc. Fish or other aquatic animals need oxygen to aerobically generate energy for body maintenance, locomotion and biosynthetic process (Van Dam & Pauty, 1995). Dissolved Oxygen (DO) is the amount of gaseous oxygen (O_2) dissolved in the water. Any oxygen adding method in to the water can be considered a type of aeration (Ahmad & Boyd,1988). DO is one of the factors which influence the feed consumption, metabolic rate and energy expenditure of fish and other aquatic animals (Dutta, 1984; Bhikajee & Gobin, 1998). Ponds generally reach the minimum DO level during the mid-night or early in the morning. However, on cloudy days the DO concentration may reach the alarming level even during the daytime. Therefore, artificial aeration is necessary to maintain adequate DO level in water bodies under culture period.

Several methods have been used to increase DO concentration in ponds. Pond aeration systems have been very popular in the field of aquaculture during the last decade. The performance testing of the aerators is very important in selecting aerators to provide cost effective and efficient aquaculture pond aeration. Paddle wheel

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aerator is most widely used (Boyd, 1998). Mechanical aeration is most common and usually the most effective means of increasing DO concentrations in ponds (Ahmad & Boyd, 1998; Moulick & Mal 2002, 2005, 2009).
Paddle wheel aerators and propeller aspirator pump aerators are most widely used (Boyd, 1988). A modified design of the paddle wheel aerator, namely spiral aerator was evaluated by Roy et al., (2017) to determine its applicability in aquaculture ponds. It was seen from their study that the least aeration cost is achievable when rotational speed of the spiral aerator is only 70 rpm for pond volumes up to 700 m^3 and 120 to 220 rpm for pond volumes exceeding 700 m^3. Diffused aerators which include propeller aspirator pump aerators and submersible aerator (1-2 HP) are more economical for ponds of size of less than 2 ha, when compared to other types of aeration system (Engle, 1989).

Comparative Performance of Different Types of Aerators

Propeller-aspirator-pump aerators, vertical pump aerators and diffused-air aeration systems are widely used in aquaculture for aeration of small ponds. Values for standard oxygen transfer rate (SOTR) and standard aeration efficiency (SAE) for various aerators are summarized in Table 1. In ponds with area less than 2 ha, the propeller-aspirator-pump aerators (1–3 HP) are found to be most economical one (Engle, 1989). Theses aerators were also found to be very effective in mixing of pond water. Kumar, Moulick & Mal (2010) found maximum SOTR and SAE to be 0.15 kg O_2/h and 0.42 kg O_2/kWh, respectively at rotational speed (N) of 2840 rpm, submergence depth (d) of 0.14 m and positional angle of 75° of the propeller shaft.

A modified design of propeller-aspirator-pump aerator is the submersible aerator (2 horse power, 3 phase, Make; Sagar Aqua Pvt. Ltd., Rajkot, India), The propeller-aspirator-pump aerator introduces atmospheric air through a rotating shaft, connected to an electric motor outside the water body and a propeller at the other end which is submerged under water. Basically the propeller rotates at a very high speed inside the water. This causes a drop in pressure inside the water. This pressure difference forces air to pass through a diffuser in the hollow shaft and enter into the water as fine bubbles. In case of submersible aerator, a submersible pump fitted with a propeller and also connected with a hollow pipe (mouth is above water), draws air from atmosphere and mixes air with water. It is presumed that this new aerator may also be useful in aquacultural ponds. To date no literature has been reported on the submerged aerator.

The main design parameters of the submersible aerators affecting aeration efficiency are (i) angular position of the propellers (α) and (ii) submergence depth of the propellers (d). In the present study, aeration performance of the submersible aerator was carried out at different α and d to determine the optimum conditions at which SAE is maximized.

Theoretical Analysis

Standard oxygen-transfer rate (SOTR) of an aerator is defined as the amount of oxygen transferred to a water body in unit time under standard conditions (water temperature = 20°C, initial DO concentration = 0 mg/L, one atmospheric pressure and clean tap water).

$$SOTR = k_La_{20} \times (C^* - C_0) \times V = k_La_{20} \times 9.07 \times V \times 10^{-3} \quad \ldots(1)$$

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where SOTR = standard oxygen-transfer rate (kg O_2/h),

k_La_{20} = overall oxygen transfer coefficient at 20°C (h^{-1}),

$k_La_{20} = k_La_T / \theta^{T-20}$,

k_La_T = overall oxygen transfer coefficient at T°C (h^{-1}),

θ = temperature correction factor = 1.024 for clean water,

C^* = saturation value of DO at test condition (mg/L),

C_0 = initial DO concentration (mg/L),

9.07 = saturated DO concentration of clean water at 20°C and standard atmospheric pressure,

V = volume of water, m^3 and

10^{-3} = factor for converting g to kg.

In most cases larger aerators will transfer more oxygen than smaller ones. A better comparative parameter is the Standard Aeration Efficiency (SAE) which is defined as the amount of oxygen transferred per unit of energy input. SAE (kg O_2/kWh) can be calculated by:

SAE (kg O_2/kWh) = SOTR/P …(2)

where P = power applied to the aerator (kW).

The actual oxygen transfer rate (OTR) of an aerator operating in a fish pond can be estimated by the following equation (Boyd, 1998):

$$\text{OTR} = \frac{SOTR\ [\alpha(1.024)T - 20\ (\beta C_S - C_P)]}{9.07} \quad \text{…(3)}$$

where C_S = saturation concentration of pond water (mg/L) at T°C,

C_P = initial DO concentration in pond water (mg/L) at T°C,

$\alpha = k_La_{20}$ pond water / k_La_{20} tap water and

β = DO saturation concentration of pond water / DO saturation concentration of tap water.

Materials and Methods

Submersible Aerator and its Specifications

Submersible aerator (2 Horse Power and 3 Phase) consists of a float, a frame, air suction pipe and submersible pump (Fig. 1). The submersible pump (Table 2) draws atmospheric air through hollow suction pipe which is connected to the propeller at the other end which is submerged in water. As per design, the propeller rotates at a speed of 2900 rpm, high enough to cause suction of air in the hollow pipe. The air passes through hollow suction pipe and enters into the water as micro-fine bubbles. The bubbles thus formed are thoroughly mixed with the water due to the turbulence created by the propeller. The aeration performance of a propeller aspirator pump aerator depends on α, d, N and the design features of the propeller (Kumar et al., 2010). An alternating current frequency-based speed controller of three-phase Emotron VSU alternating current drive model (VSU48-004-20CNB; Crompton Greaves Limited, Kolkata, India) was used to adjust the rotational speed and measured power of the aerator.

Modification of the Aerator

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For the purpose of studying performance of the aerator at different α and at different d of shaft, the aerator was modified to have the provision for changing the angle of propeller and submergence depth of the propeller (Fig. 2). Performance evaluation of aerator before its modification was done to compare the SOTR and SAE values before and after modification. By modifying, the α could be varied from 0º to 75º at an interval of 15° and d could be varied from 300 mm to 600 mm at an interval of 50 mm.

Experimental Tank

Brick masonry tank of inner dimension of 4 m × 4 m × 1.5 m located in the Aquacultural Engineering Section, Agricultural & Food Engineering Department, IIT Kharagpur was used for testing the performance of submersible aerator. The tank was provided with asbestos sheet roof to avoid contamination as well as interference due to rain. On one side of the tank bottom an outlet valve is provided for draining out the water whenever required.

Dissolved Oxygen Meter

Dissolved oxygen meter (Make: YSI Professional Plus 20) was used to measure the DO concentration during the experiments. The temperature was also recorded along with the DO readings by using the thermometer attached to the DO meter. The YSI Professional Plus 20 DO meter works on the polarographic principle. It consists of a polarographic probe, which uses gold or platinum as the cathode and silver as anode. Polarizing voltage is applied to the cathode to cause the reduction of oxygen within the sensor. Oxygen is consumed at the cathode according to the reaction:

$O_2 + 2\ H_2O + 4e^- = 4\ OH^-$

Chemicals Used in the Experiment

To analyze the performance of the aerator, water in the experimental tank was initially deoxygenated and DO was lowered down to 0 mg/L (approx.). For this purpose, 10 mg of sodium sulphide (Na_2SO_3) was used for lowering of 1 mg of O_2 per litre and for each litre of water. Simultaneously 0.1 mg of cobalt chloride ($CoCl_2$) was used as a catalyst for lowering one mg of O_2 per litre of water.

Aeration Experiments

Aeration experiments were conducted in concrete tanks using clean tap water. Initially the tap water was deoxygenated using sodium sulfite and cobalt chloride as mentioned earlier (Boyd, 1998). Thereafter the aerator was operated at the desired conditions and simultaneously readings were taken at regular intervals till DO increased from zero to at least 90% saturation. DO measurements were taken using two YSI Professional Plus 20 DO meter (YSI, Yellow Springs, OH, USA). At least twenty DO readings at equal intervals were taken. The DO deficit was computed for each time. The slope of the best fit line, when natural logarithms of DO deficits (Y) were plotted against the time of aeration (X), produced oxygen transfer coefficient at the test water temperature. Finally the oxygen-transfer coefficient was adjusted to 20ºC using the equation:

$$k_La_{20} = k_La_T / 1.024^{(T-20)} \quad \ldots (4)$$

SOTR and SAE were calculated using Eqn. (1) and (2) respectively.

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Experimental Design

The procedure for determining the optimum α and d of submersible aerator at which aeration efficiency becomes the maximum are described in this section.

Angle Position and Optimization of the Propeller Shaft

Aeration tests were conducted keeping N = 2900 rpm and d = 450 mm as constants, the optimum α of aerator at which the aerator has the maximum aeration efficiency was found out by conducting aeration experiments at different α of aerator: viz. 0º, 15º, 30º, 45º, 60º and, 75º. The volume of water to be used for testing of aerator was found out by maintaining the condition of power-volume ratio i.e. $P/V \leq 0.1$ kW/m^3 (Elliot, 1969). Volume of water used for testing was 16 m^3.

Submergence Depth Optimization of the Propeller Shaft

Setting α at optimum value obtained from previous tests, the optimization of d was done by conducting aeration tests at different d of propeller shaft of aerator: viz. 300, 350, 400, 450, 500, 550 and 600 mm. The N of the propeller and volume of water were kept at 2900 rpm and 16 m^3 respectively.

Results

Performance Evaluation of the Aerator Prior to Modification

To compare the performance of modified aerator (Table 3) with that of the original aerator, SAE and SOTR of the original aerator were measured. The α, d and N were 0º, 300 mm and 2900 rpm respectively.

Different Angle Position of the Propeller and Effect on Performance of Aerator

Keeping N at 2900 rpm and d at 450 mm, aeration experiments were conducted at different α of submersible aerator and results obtained by conducting experiments are presented in Table 4**.**

It is seen from Table 4 that the values of k_{La20} and SOTR, increase with the increase in α. This is because as the α increases, the hollow shaft from where the air enters, directs the air towards the bottom of the tank. This facilitates the air bubbles to remain inside the tank for a longer duration. Increasing the angle helps the bubbles move towards the bottom instead of moving parallel to the surface of the water. The relationship between SAE and α of the submersible aerator is shown in Fig. 3. It is seen from the figure that the SAE increases with the increase in α. The relationship could be expressed by a second order polynomial equation. The maximum SAE was obtained at 75º.

Keeping the N of aerator at 2900 rpm and α at 75º (the optimum values obtained from previous experiments) as constants, experiments were conducted (Table 5) at different d: 300, 350, 400, 450, 500, 550, and 600 mm. The relationship between SAE and d of the submersible aerator is shown in Fig 4. It can be seen from the figure that the variation of SAE with different d does not follow any particular trend. However, it follows almost a declining trend and could be fitted with a second order polynomial equation. However, the highest SAE value of

0.616 kg O_2/kWh is obtained for the aerator at 350 mm submergence depth. After that the SAE values declined as the power consumption increased with the increases in submergence depth.

Comparison of Performance before and after Modification

Before modification of aerator, SOTR = 0.346 kg O_2/h

SAE = 0.320 kg O_2/kWh

After optimization of geometric and dynamic parameters of aerator,

SOTR = 0.429 kg O_2/h

SAE = 0.616 kg O_2/kWh

Percentage increase in SOTR after optimization = [(0.429 – 0.346)/0.346]*100

= 23.98 %

Percentage increase in SAE after optimization = [(0.616 – 0.320)]/0.320]*100

= 92.50 %

Discussion

According to the research, the aeration performance of the submersible aerator depends on α, d, N and other design features of the propeller shaft. In order to enhance the efficiency of the aerator, optimization of the above parameters were performed. Out of these parameters, α and d of the propeller shaft were optimized in order to increase the efficiency. The N was kept at maximum, because reducing the N, decreased the efficiency (Kumar et al., 2010). Design of the propeller shaft was not varied.

To evaluate the optimum α, experiments were conducted at different α: 0, 15, 30, 45, 60, and 75^o, keeping the N at 2900 rpm and d of the propeller at 450 mm. The results showed that SOTR and SAE attained the maximum values at α = 75^o. In a similar way to evaluate the optimum d, experiments were conducted at different d: 300, 350, 400, 450, 500, 550, and 600 mm, keeping the N at 2900 rpm and α at 75^o as obtained from previous experiments.

The optimized values of SAE (0.616 kg O_2/kWh) and SOTR (0.429 kg O_2/h) were obtained at α = 75^o and d = 350 mm. The respective values before optimization were 0.320 kg O_2/ kWh and 0.346 kg O_2/h. Thereby, the SAE of the submerged aerator increased by 92.5% after modification.

Conclusions

The following conclusions can be drawn based on the above study:

1. The SAE and SOTR of the original submerged aerator are 0.320 kg O_2/kWh and 0.346 kg O_2/h respectively.
2. SAE and SOTR increase with the increase in α and attain maximum values at 75^0.
3. SAE increases marginally with the increase in d from 300 to 350 mm and then starts decreasing.
4. The optimized values of SAE and SOTR are 0.616 kg O_2/kWh and 0.429 kg O_2/h respectively at α = 75^o and d = 350 mm.

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Table 1. Values of Standard oxygen transfer rate (SOTR) (kg O_2/h) and Standard aeration efficiency (SAE) (kg O_2/kWh) for different electric aerators used in aquaculture (Boyd and Ahmad, 1987 and Kumar, 2014).

Type of aerator	Number of aerators	Average values of SOTR	SAE[1]	
			Average	Range
Paddle wheel	24	12.85	2.2	1.1 - 3.0
Propeller-aspirator-pump	11	12.25	1.6	1.3 – 1.8
Vertical pump	15	5.6	1.4	0.7 - 1.8
Pump sprayer	3	13.2	1.3	0.9 – 1.9
Diffused-air	5	2.25	0.9	0.7 – 1.2

[1]SAE is based on estimated brake power

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Table 2. Specifications of the aerator

Materials	Sagar Aqua Company, Gujurat, India.
Pump (1 unit)	Submersible pump of 2 hp, 3 phase (450 ± 10 V), 50 Hz capacity attached with 20 m electric cable
Speed	2900 rpm
Frame (1 unit)	Made of S.S. 304 with powder coated
Hollow suction pipe (1 unit)	UPVC
Bolt and nut (1 set)	Made of S.S. 304
Float (2 unit)	Blow molded type, weighs 7 kg ± 100 g, made of HDPE

Table 3. Performance of the original aerator having d (300 mm) and α (0º)

Temperature (°C)	k_La_T (h^{-1})	k_La_{20} (h^{-1})	SOTR (kg O_2/h)	SAE (kg O_2/kWh)
24.4	2.652	2.389	0.346	0.320

Table 4. Performance of the submersible aerator at d (450 mm) and different α

Angle of the propeller shaft, (α^0)	Temperature (°C)	k_La_T (h^{-1})	k_La_{20} (h^{-1})	SOTR (kg O_2/h)	SAE (kg O_2/kWh)
0	21.4	2.364	2.358	0.338	0.392
15	20.5	2.700	2.668	0.387	0.456
30	20.4	2.706	2.674	0.388	0.458
45	20.1	2.526	2.903	0.421	0.498
60	20.4	3.030	3.001	0.435	0.515
75	**20.1**	**3.072**	**3.067**	**0.444**	**0.526**

Table 5. Performance of the submersible aerator at 75º angle of the propeller α, and different submergence depths d

Submergence Depth, d (mm)	Temperature (°C)	k_La_T (h^{-1})	k_La_{20} (h^{-1})	SOTR (kg O_2/h)	SAE (kg O_2/kWh)
300	20.3	2.844	2.823	0.409	0.601
350	**20.3**	**2.982**	**2.960**	**0.429**	**0.616**
400	19.9	3.120	3.127	0.453	0.593
450	20.1	3.072	3.067	0.444	0.526
500	19.4	2.712	2.586	0.375	0.414
550	19.3	2.832	2.879	0.417	0.445
600	18.6	2.562	2.648	0.384	0.342

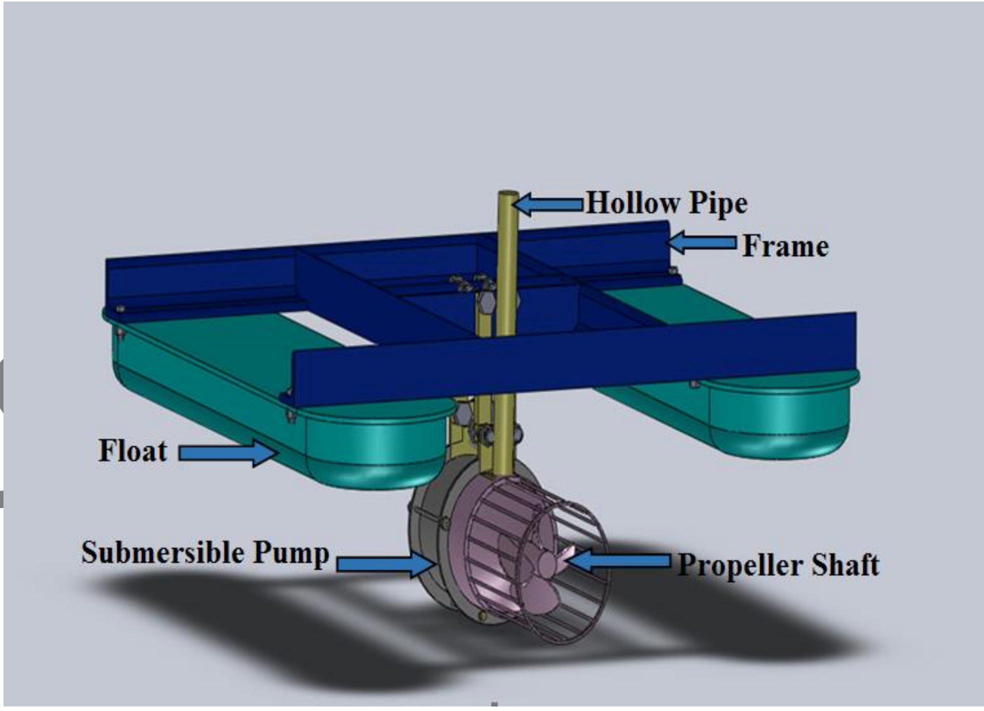

Figure 1. A view of submersible aerator before modification

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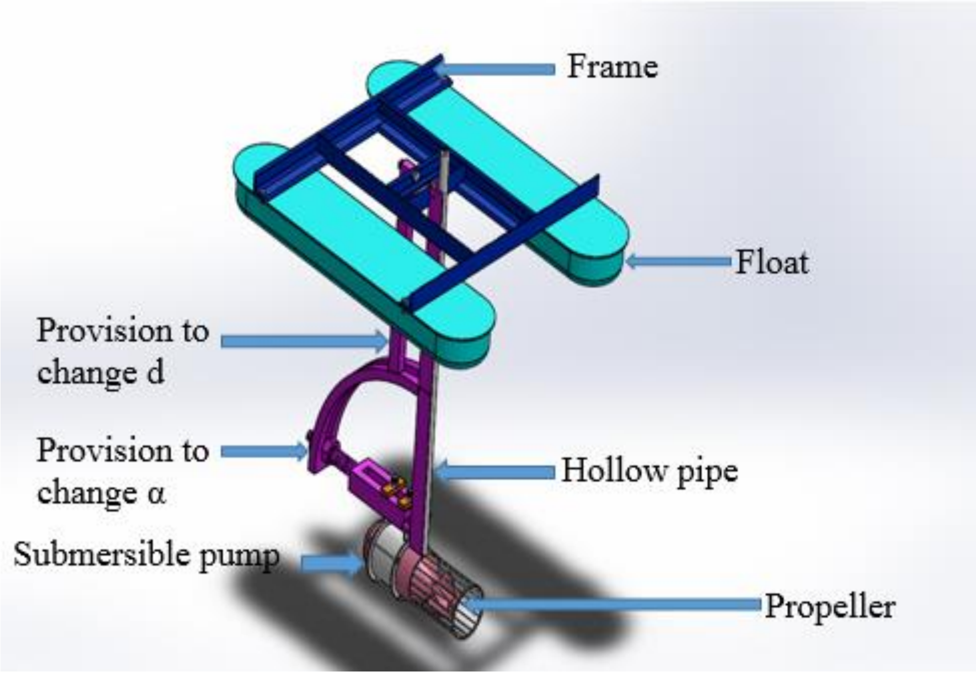

Figure 2. A view of submersible aerator after modification

Figure 3. Different views of the modified aerator

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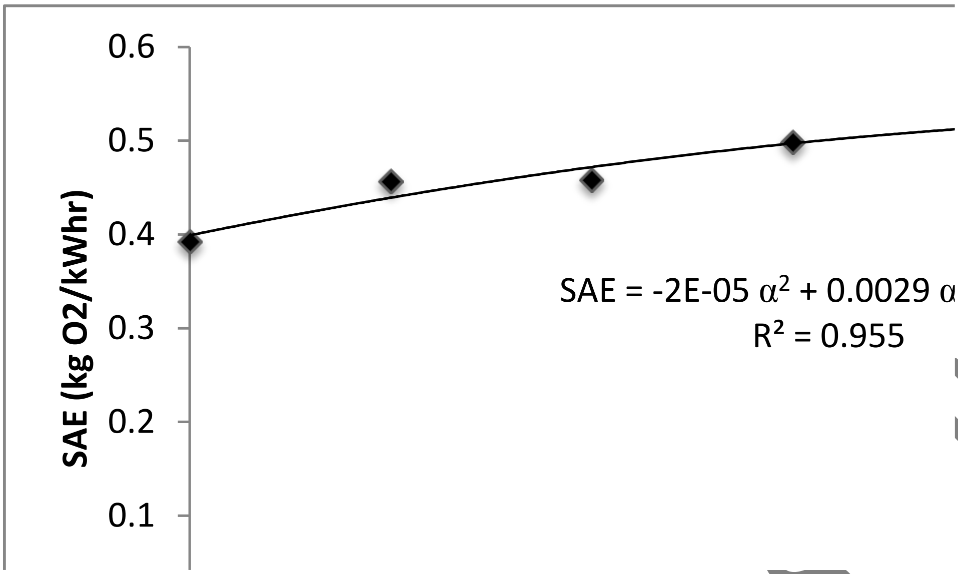

Figure 3. Variation of SAE with different angles of the propeller (α) of submersible aerator

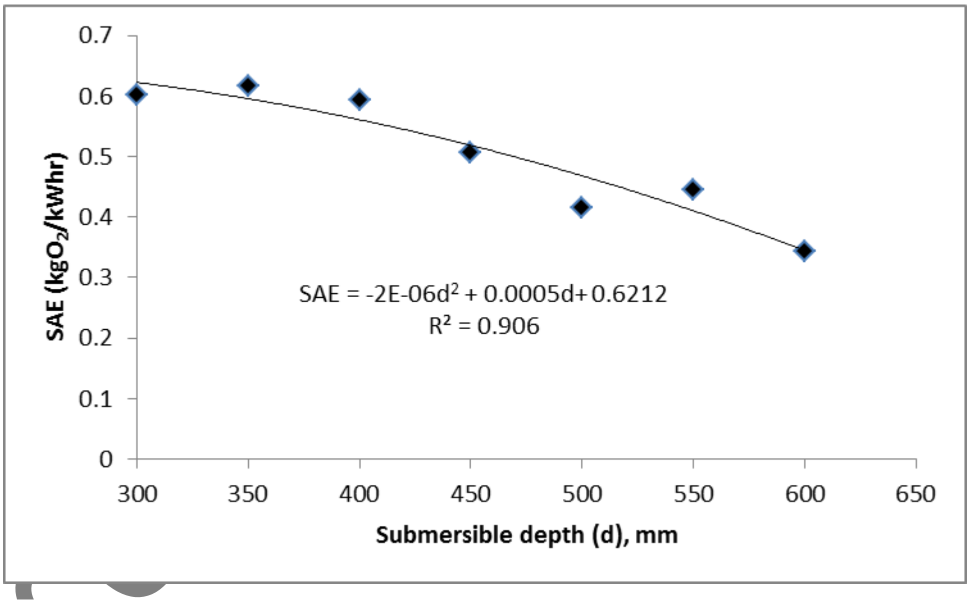

Figure 4. Variation of SAE with different angles of the propeller shaft (α) of submersible aerator

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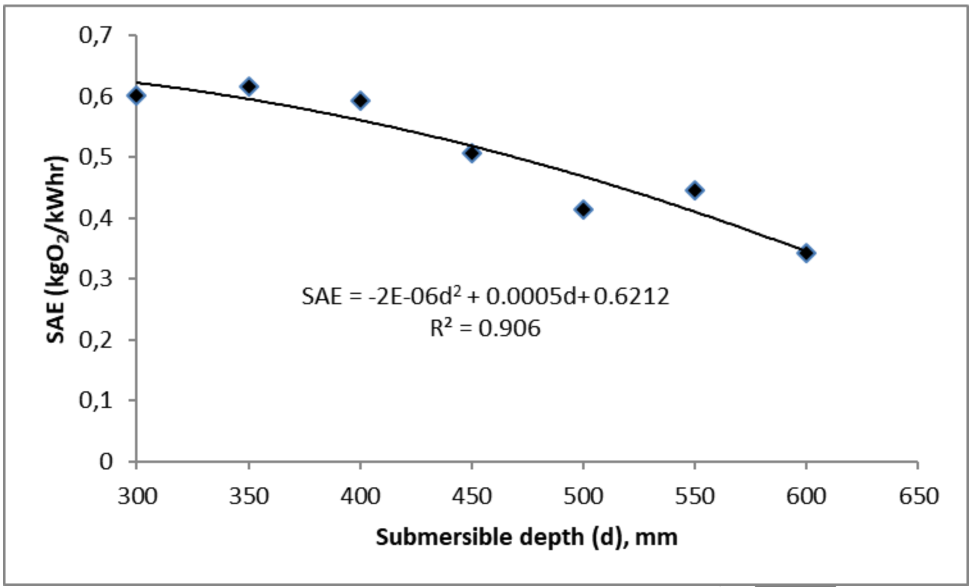

Figure 5. Variation of SAE with different submersible depth of the propeller shaft