The development of furrower model blade to paddlewheel aerator for improving aeration efficiency

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Abstract. The successful of intensive aquaculture is strongly influenced by the ability of the farmers to overcome the deterioration of water quality. The problem is low dissolved oxygen through aeration process. The aerator device which widely used in pond farming is paddle wheel aerator because it is the best aerator in aeration mechanism and usable driven power. However, this aerator still has a low performance of aeration, so that the cost of aerator operational for aquaculture is still high. Up to now, the effort to improve the performance of aeration was made by two-dimensional blade design. Obviously, it does not provide the optimum result due to the power requirements for aeration is directly proportional to the increase of aeration rate. The aim of this research is to develop three-dimensional model furrowed blades. Design of Furrower model blades was 1.6 cm diameter hole, 45° of vertical angle blade position and 30° of the horizontal position. The optimum performance furrowed model blades operated on the submerged blade 9 cm with 567.54 Watt of electrical power consumption and 4.322 m³ of splash coverage volume. The standard efficiency aeration is 2.72 kg O₂ kWh⁻¹. The furrowed model blades can improve the aeration efficiency of paddlewheel aerator.

1. Introduction
Aeration is a mechanism of adding some amount of oxygen into water to provide sufficient amount of oxygen. Aeration is carried out by increasing water and air contact using aerator device. One type of aerator device which widely used in pond farming is paddle wheel aerator [1]. Paddlewheel aerator is considered as the most appropriate aerator device due to aeration mechanism and wide usable driven power [2]. Standardized aeration efficiency is directly proportional to the standard oxygen transfer rate and inversely proportional to the power consumption.

Aeration rate is influenced by water and air surface contact, differential oxygen concentration, film surface coefficient and turbulence [3]. Geometry, size and wheel speed affect aeration performance [4]. Largest size tends to have higher aeration which coincides followed by higher driven power needs due to higher drag force. This condition causes the certain problem in utilizing paddle wheel aerator as
it causes increasing operational cost including electrical and fuel consumption. Electric power consumption is an important parameter in utilization paddlewheel aerator because affected on operating costs. Also, to provide the value of the energy consumption needs in the factual, the measurement of electrical power is also a reference for the farmers in selecting the aerator [5].

Up to now, the effort to improve the performance of aeration was made by two-dimensional blade design. Obviously, it does not provide optimal result because of the power requirements for aeration is directly proportional to the increase of aeration rate. Therefore, the aim of this research is to develop the model of a three-dimensional furrowed model blade and operational condition for improving aeration efficiency.

2. Materials and Methods

2.1. Materials

2.1.1. Furrower model blades.
Furrower model blades are based on the geometry of the arch blade wheel optimization results that have been done before [6], the hole diameter was 16 mm, 45˚ of vertical angle blade position and 30˚ of horizontal position as shown in Figure 1. The blade consists of eight pieces with the outer width was 174 mm, the length 176 mm and 300 mm for the radius of curvature of the blade.

![Figure 1. Rim and furrowed model blades](image)

2.1.2. Paddlewheel test unit.
Structural design paddlewheel consists of a frame, reduction rotation transmission systems, paddlewheel blades and laying the instrument. The frame using the steel angle with the dimensions, shape, and strength customized with support and load other components. The motor used is 1 phase AC electric motor with a power of 1 HP at 1440 rpm rotational speed.

2.2. Procedure

2.2.1. Treatments variations.
The tests were conducted in the freshwater pool with dimensions of length 350 cm, 200 cm width with a water depth of 40 cm. Submerged variations blade is done by changing the height position paddlewheel support. The tests were conducted at a rotational speed of 154 rpm with the blade submerged 6, 9, and 12 cm.
2.2.2. **Torque measurement.**
Torque measurement was done by using a strain gauge mounted on the wheel shaft. The sensor was connected to the strain amplifier (DAS-406B DC Strain Amp) through the slip ring, and the bridge box was recorded by using data loggers (minilab 1008) and stored in the computer (Figure 2). Measurement data in the form of a voltage (mVolt) was converted to strain (μst) and torque measurement values (N·m) with calibration values that have been done before.

![Figure 2. Rim and furrowed model blades](image)

2.2.3. **Power measurement.**
Paddlewheel power measurement was done by measuring the electrical power consumption of electric motors using Ammeter (DO2A) which was connected to an electrical outlet. Reading the power measurement value (Watt) was done by using a digital video camera recording on display Ammeter. Rated power was taken on the average value that often was showed from the reading video playback recording for each treatment testing.

2.2.4. **Splash coverage volume measurement.**
Splash coverage volume was done by taking the recorded images used a digital camera from the front side and side the wheel at the time of testing. Then, the digital image was processed by using a CAD program to create segments (grid), which the splash coverage volume was the number of multiple results of segments area at the front side water splash with the side of water splash.

2.2.5. **Standard aeration efficiency (SAE) measurement.**
The SAE test was conducted according to ASCE standard [7]. The test was done in pool size 4x5x1.25 m and water depth 1 m. Paddlewheel was used to stir sodium sulfite with water until it reached 0% saturation or below 1 mg l⁻¹. Measurements of DO and water temperature using Oxygen meter. Measurements of DO increases begin when DO water started to increase until saturation is 80%.

3. **Results and Discussion**
The water splash produced visible from the front and side the wheel of the submerged blade 12 cm as shown in figure 3.

![Figure 3. The image of water splash and calculation segment of splash coverage volume.](image)
Torque occurred, electrical power consumption and splash coverage volume produced at different blade submerged shown in table 1.

Table 1. Performance test results at different blade submerged.

| Blade submerged (cm) | Torque (N·m) | Power consumption (Watt) | Splash coverage volume (m³) |
|---------------------|--------------|--------------------------|-----------------------------|
| 6                   | 45.85        | 552.19                   | 3.754                       |
| 9                   | 47.13        | 567.54                   | 4.322                       |
| 12                  | 48.28        | 581.42                   | 4.095                       |

The increasing of blade submerged resulted in greater torque and increasing the power consumption, while the splash coverage volume had optimum value at the blade 9 cm.

The increase in torque due to changes blades submerged of 6 cm to 9 cm and 12 cm respectively 2.79 % and 5.30%, while the electrical power consumption were 2.78% and 5.29%. This is caused by the increase of water mass that driven by the paddlewheel, thus increasing the drag force of the blade wheel as revealed by Kang (2004). While the difference between the increase in torque with the electric power is due to lose in the reduction system.

Splash coverage volume maximum occurred in submerged blade 9 cm was 4.322 m³ (up 15.13%) with 567.54 Watt power consumption, whereas in 12 cm increased by 9.08%. Submerged blade 6 cm have little mass of water to be splashed, whereas in 12 cm of displaced water mass was too large, thus slowing rotation due to the great drag force of blade. The coverage volume is obtained approaching splash coverage volume of Taiwan paddlewheel models (two-wheel) 4.356 m³ with 852 Watt power consumption.

Based on the ratio of the electric power consumption, showed that furrowed model blades have a good effect on reducing the drag force of the blades. This is as mentioned by Munson et al. (2006) that the drag coefficient is determined by the geometry and dimensions of an object. While the increase in volume is obtained by the spread of water splash due to furrowed blades. Reducing of water collision momentum due to the tilt angle of the blade overcome by a rotational speed of paddlewheel was 154 rpm compared to Taiwan paddlewheel models was 120 rpm. This is as stated by Park et al. (2014) and Liu and Peymani (2015) that the power consumption and the flow rate increased directly proportional to the depth of submerged blades and increasing paddlewheel rotation.

The standard aeration test at pool volume 20 m³ and water temperature 28 ºC, obtained saturation dissolved oxygen 9.07 mg l⁻¹ and 588 Watt of electric power used, so obtained the relation of natural logarithm (Ln) deficit DO as shown in figure 4.

Figure 4. Graph for calculation of aerator SOTR test
The standard oxygen transfer rate (SOTR) was $1.60287\ \text{kg O}_2\ \text{h}^{-1}$, and the standard aeration efficiency (SAE) was $2.72\ \text{kg O}_2\ \text{kWh}^{-1}$. This achievement was better than the previous, the average SAE was $2.2\ \text{kg O}_2\ \text{kWh}^{-1}$ [3]. The increase of SAE is obtained due to the decrease in drag force of blades use the angle blades so reduces the consumption of electrical power. However, the splash of water remains widely as a result of angle blades, so the water spread. It has shown the efficiency of standard aeration proportional to the rate of oxygen transfer and inversely to the consumption of electric power as mentioned by Lekang (2007). The performance was better than the standard aeration efficiency of the standard model paddlewheel of Taiwan and the previous development wheel.

4. Conclusions
The paddlewheel of Furrower model blade consumed less electrical power but produced greater splash coverage volume. Design of Furrower model blades was 1.6 cm diameter hole, 45° of vertical angle blade position and 30° of the horizontal position. The standard oxygen transfer rate and standard aeration efficiency were produced $1.60\ \text{kg O}_2\ \text{h}^{-1}$ and $2.72\ \text{kg O}_2\ \text{kWh}^{-1}$. The furrowed model blade was able to improve the aeration efficiency of the paddlewheel.

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