Simulation on Blade Geometry and Operational Condition toward Torque Requirement and Drag Force in Paddle Wheel Aerator

Samsul Bahri, Radite P.A. Setiawan, Wawan Hermawan, Muhammad Zairin Junior

Abstract—Power required by paddle wheel aerator is highly depend on blade geometry and operational conditions. In order to predict the correlation, simulation of blade geometry and several operational conditions againts torque requirement and drag force in a paddle wheel aerator was carried out. The experimental the blade was 56 cm diameter, 20 cm width of double trapezoid (5 cm of top width and 15 cm of bottom width), 15 cm height and formed 30^0 angle to the rim with the curvature radius of blade was 40 cm. For simulation purpose, Computational Fluid Dynamic (CFD) software with external flow was used in this research. The fluid flew opposite to the direction of speed rotational which was set at 115, 135 and 154 rpm for every immersion depth of 4, 6 and 8 cm. Simulation showed that the lowest torque was 12.48 Nm which occurred at 1.6 cm hole diameter and blade angle of 30^0, 4 cm of immersion depth and wheel speed set at 115 rpm. The lowest drag force coefficient was 0.80 that occurred at 1.6 cm hole diameter, blade angle of 30^0 and immersion depth at 8 cm. Average torque reduction at 15^0 and 30^0 of blade angle was 6.73% and 22.27%, respectively. Average torque reduction which produced by different hole diameter from 0.8 cm to 1.2 cm was 9.06% and 0.8 cm to 1.6 cm was 12.31%.

Index Terms— Aerator, paddle wheel torque, paddle wheel drag, CFD, blade angle, hole diameter, immersion depth.

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 (Laksitanonta 2003). Paddle wheel aerator is considered as the most appropriate aerator device due to aeration mechanism and wide usable driven power (Romaire & Merry 2007).

Aeration rate is influenced by water and air surface contact, differential oxygen concentration, film surface coefficient and turbulence (Boyd 1998). Geometry, size and wheel speed affect aeration performance (Peterson & Walker 2002; Moulick *et al*. 2002). Higher size tends to have higher aeration which simulataneously followed by higher driven power needs due to higher drag force. This condition causes certain problem in utilizing paddle wheel aerator as it causes increasing operational cost including electrical and fuel consumption.

Various models of paddle wheel aerator are offered in market. Aerator made by Taiwan is widely used by consumers due to affordable price, light in weight and corrosion-resistant but has low efficiency (Wyban 1989). Aerator that was designed and fabricated by Taiwan has *SAE* (standard aeration efficiency) value of 1.063 kg O_2 kW h^{-1} (Peterson & Walker 2002). Bhuyar *et al* (2009) designed aerator with SAE value 2.269 kg O_2 kWh^{-1}. The most appropriate paddle wheel aerator was designed by Moore and Boyd with *SAE* value 2.54 kg O_2 kWh^{-1}. Some of fabrications use aerator design with specification 2.25-7.5 kW and *SOTR* 17.4- 23.2 kg O2 h^{-1} and average value of SAE was 2.2 kg O_2 kW h^{-1} (Moore & Boyd 1992).

Up to now, the design of two dimensional blade has not been yet optimized as power required for aeration is linear with aeration rate increment. Therefore, development should focus on blade geometry especially in diameter hole and blade angle. In this study simulation was carried out to determine the lowest magnitude of drag force and torque for every immersion depth and wheel speed.

1.1 Torque Requirement

Torque (T) is a quantitative measure of a couple to rotate or change the motion of an object. Torque that required by aerator is determined by the force applied and the perpendicular distance where the force is applied. Correlation between the magnitude of torque and the magnitude of power (*P*) of the aerator to rotate paddle wheel aerator at certain angular velocity (ω) is calculated as follows:

$$P = T\,\omega \qquad (1)$$

1.2 Blade's Drag Force

In fluid dynamic, drag force refers to resistance force acting to solid object flowing into fluid (liquid or gas). The most common drag force is composed of friction force that parallel to the object's surface and pressure force that perpendicular to object's surface. In a solid object that flows through fluid, drag force is a magnitude of fluid dynamic force that acting opposite to the relative motion.

Total drag force of an object is characterized by dimensionless number i.e. drag coefficient. The magnitude of drag coefficient is determined by geometry and dimension of the object as well as the force applied. Drag force depends on the properties such as drag force applied (*Fd*), fluid density (*ρ*), speed of the object (*v*) and blade surface area which computed below

$$C_d = 2F_d / \rho v^2 A \qquad (2)$$

- *Samsul Bahri is currently pursuing doctoral degree program of Agricultural Engineering Science, Bogor Agricultural University, Indonesia, and is lecturer at Mechanical Engineering Department, Lhokseumawe State Polytechnic, Indonesia, PH-085277633977. E-mail: soel_73@yahoo.com*
- *Radite P.A. Setiawan. Department of Mechanical and Biosystem Engineering, Bogor Agricultural University, Indonesia*
- *Wawan Hermawa. Department of Mechanical and Biosystem Engineering, Bogor Agricultural University, Indonesia*
- *Muhammad Zairin Junior, Department of Aquaculture, Bogor Agricultural University, Indonesia*

International Journal of Scientific & Engineering Research Volume 6, Issue 2, February-2015
ISSN 2229-5518

2 WHEEL DESIGN

Wheel consisted of 8 trapezoid blades with 56 cm of diameter. Blade formed an angle of 30^0 toward rim with the curvature radius of blade was 40 cm. The size of the blade was 20 cm of width (top width was 5 cm and bottom width was 15 cm) and 15 cm of height (Figure 1).

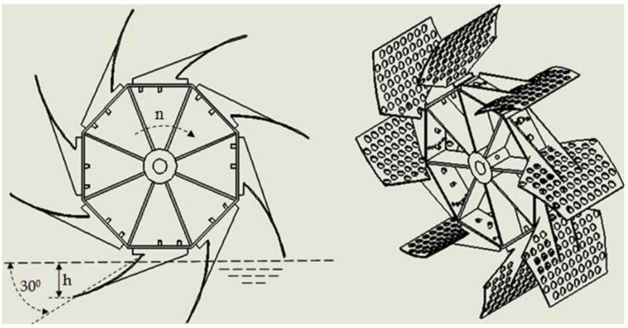

Figure 1. Rim and blade

Wheel was made in three different of holes diameter i.e. 0.8 cm (104 holes per blade), 1.2 cm (64 holes per blade) and 1.6 cm (40 holes per blade). Blade was attached on rim with three variance of angle positions i.e. 0^0, 15^0 and 30^0 as shown in Figure 2.

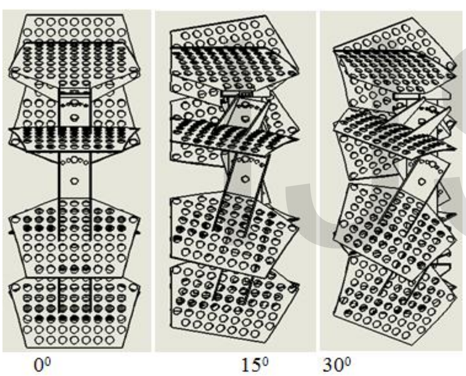

Figure 2. Blade angle position

3 SIMULATION

3.1 Experimental Set Up

Simulation was carried out at different immersion depth and wheel speed. Immersion depth (*h*) was tested at 4, 6 and 8 cm. Wheel speed (*n*) was tested at 115, 135 and 154 rpm.

3.2 Simulation Process

Simulation was performed by employing computational fluid dynamic software. The type of analysis was external flow with x-axis as the reference base. Computational domain sized of 75x30x16 cm with meshing domain 2 mm (Figure 3). This process used water at temperature 25 ^{0}C and pressure 1 atm with density 997 kg/m^3 and dynamic viscosity 0.00089 Pa^2 s. Simulation process was carried out at motionless wheel where the fluid flew opposite to the wheel with linear velocity 3.372 m/s, 3.958 m/s and 4.515 m/s. The main results of the analysis were force, torque and contour flow reacted.

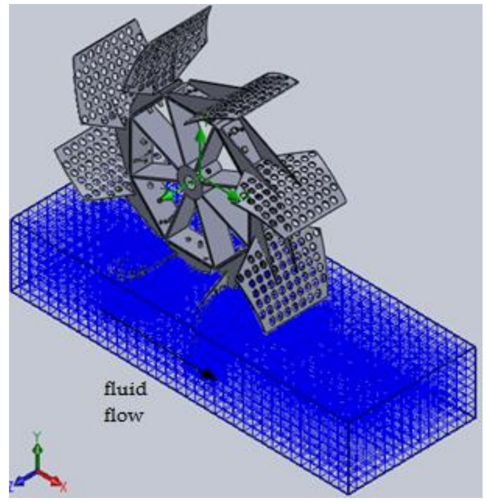

Figure 3. Meshing domain

4 RESULT AND DISCUSSION

4.1 Torque Requirement

Torque requirement at different experimental set up showed different result. At 115 rpm of wheel speed, the lowest torque was 12.48 Nm which occurred at immersion depth of 4 cm with hole diameter of 1.6 cm and 30^0 blade angle position. The highest torque was 32.24 Nm which occurred at 8 cm immersion depth with 0.8 cm hole diameter and 0^0 blade angle position (Figure 4).

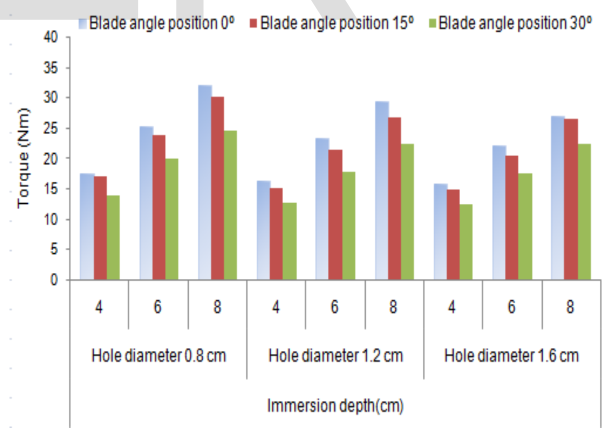

Figure 4. Wheel torque at speed of 115 rpm

At 135 rpm of wheel speed, the lowest torque was 17.21 Nm which occurred at immersion depth 4 cm with hole diameter 1.6 cm and angle position 30^0. The highest torque was 44.41 Nm which occurred at 8 cm immersion depth with hole diameter 0.8 cm and angle position of 0^0 (Figure 5).

International Journal of Scientific & Engineering Research Volume 6, Issue 2, February-2015
ISSN 2229-5518

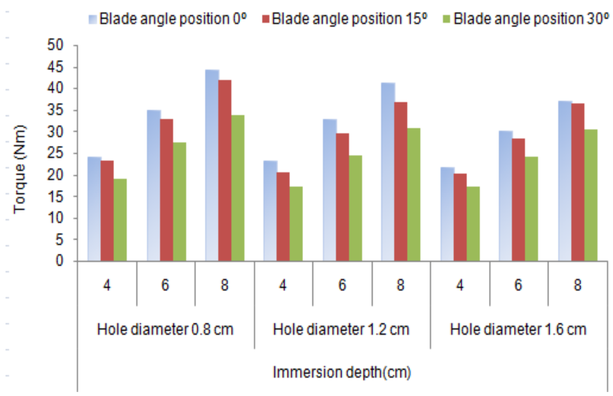

Figure 5. Wheel torque at speed of 135 rpm

At 154 rpm of wheel speed, the lowest torque was 22.41 Nm which occurred at immersion depth of 4 cm with hole diameter 1.6 cm and angle position 30^0. The highest torque was 57.85 Nm which occurred at 8 cm immersion depth with 0.8 cm hole diameter and 0^0 blade angle position (Figure 6).

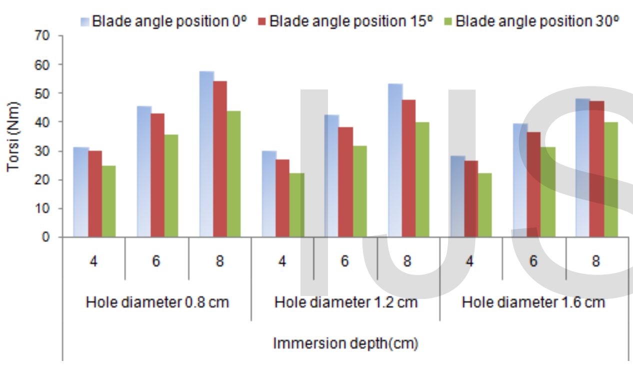

Figure 6. Wheel torque at speed of 154 rpm

Blade angle position variance reduced torque requirement. At blade angle 15^0, torque requirement was reduced by 5.19%, 9.70% and 5.31% at 0.8, 1.2 and 1.6 cm of hole diameter, respectively. At blade angle 30^0, torque requirement was reduced by 22.10%, 24.81% and 19.88% at hole diameter of 0.8, 1.2 and 1.6 cm, respectively (Figure 7).

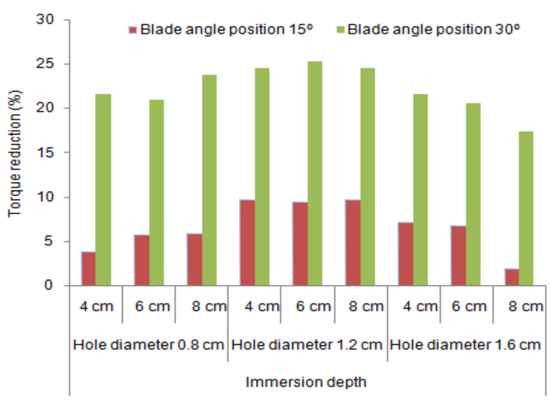

Figure 7. Torque reduction at each angle position of 15^0 and 30^0

Hole diameter educed torque requirement. At hole diameter of 1.2 cm,' torque was reduced by 6.49%, 10.95% and 9.73% at angle position 0^0, 15^0, 30^0, respectively. At hole diameter of 1.6 cm, torque was reduced by 13.07%, 13.24% and 10.63% at angle position of 0^0, 15^0, 30^0, respectively (Figure 8). Those torque reduction was almost similar to the reduction of blade surface area i.e. 10.57% for hole diameter 1.2 cm and 14.57% for hole diameter 1.6 cm.

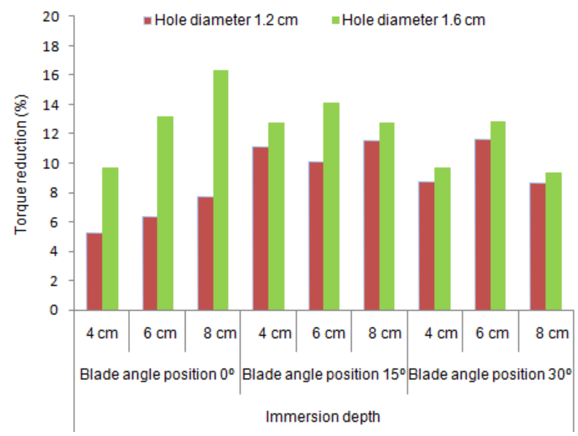

Figure 8. Torque reduction at hole diameter 1.2 cm and 1.6

Those results showed that torque requirement was decreasing along with the increasing blade angle and increasing size of diameter hole. Based on the torque requirement and using equation 1, the magnitude of power for all experiments ranging between 0.15 – 0.9 kW. This indicated that the aerator designed in this research had lower power requirement compared to commonly used fabricated aerator which ranges between 2.25-7.7 kW (Moore & Boyd 1992).

4.2 Drag Force

Drag force applied on each blade at each experiment showed different result. At wheel speed of 115 rpm, the lowest drag force was 63.32 N which occurred at 4 cm immersion depth, hole diameter 1.6 cm and angle position of 30^0. The highest drag force was 155.02 N which occurred at 8 cm immersion depth, hole diameter 0.8 cm and angle position of 0^0 as shown in Figure 9.

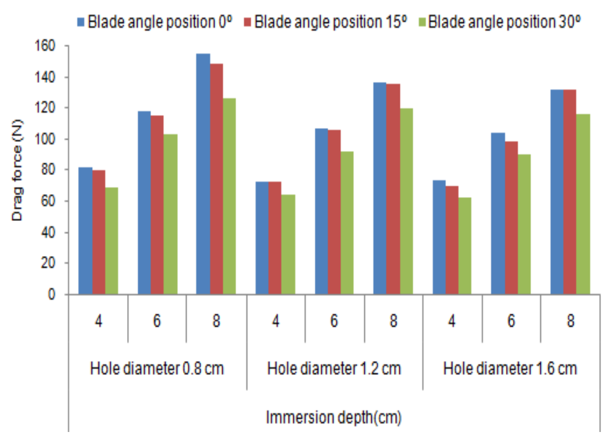

Figure 9. Drag force at wheel speed of 115 rpm

International Journal of Scientific & Engineering Research Volume 6, Issue 2, February-2015
ISSN 2229-5518

At wheel speed of 135 rpm, the lowest drag force was 86.01 N which occurred at 4 cm immersion depth, hole diameter 1.6 cm and angle position of 30^0. The highest drag force was 213.65 N which occurred at 8 cm immersion depth, hole diameter 0.8 cm and 0^0 blade angle position (Figure 10).

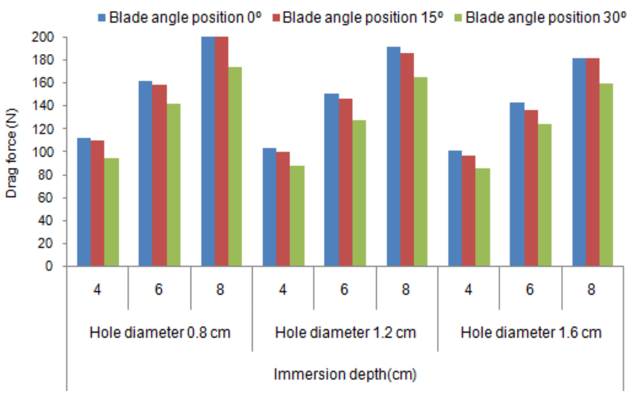

Figure 10. Drag force at wheel speed of 135 rpm

At wheel speed of 154 rpm, the lowest drag force was 112.03 N which occurred at 4 cm immersion depth, hole diameter 1.6 cm and angle position of 30^0. The highest drag force was 278.41 N which occurred at 8 cm immersion depth, hole diameter 0.8 cm and angle position of 0^0 as shown in Figure 11.

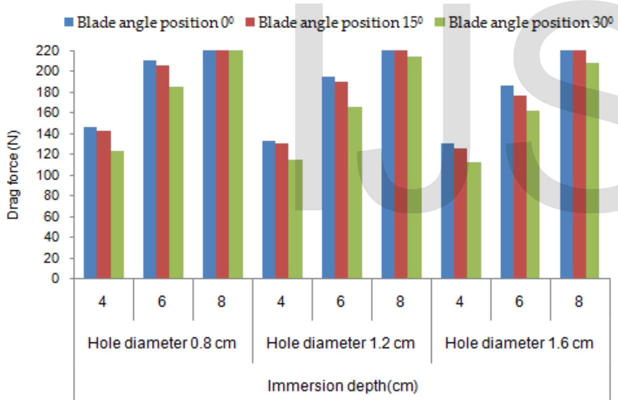

Figure 11. Torque at wheel speed of 154 rpm

According to the result of drag force simulation, it indicated that drag force applied on the blade was decreasing along with the increasing of blade angle and increasing size of hole diameter.

The drag force coefficient (Cd) derived from every experiments showed different magnitude. Table 1 shows average drag force coefficient at immersion depth of 4 cm. The smallest coefficient was 1.25 which occurred at hole diameter 1.6 cm and 30^0 blade angle position. Conversely, the highest drag force coefficient was 1.63 which occurred at hole diameter 0.8 cm and angle position of 0^0 (Table 1).

Table 1 Drag force coefficient at immersion depth of 4 cm

Hole diameter	Cd at each blade angle position		
	0^0	15^0	30^0
0.8 cm	1.63	1.60	1.38
1.2 cm	1.49	1.46	1.29
1.6 cm	1.47	1.41	1.25

At immersion depth of 6 cm, the smallest drag coefficient was 1.00 which occurred at hole diameter 1.6 cm and angle position of 30^0. The highest drag force coefficient was 1.31 which occurred at diameter hole 0.8 cm and blade angle position of 0^0 as shown in Table 2.

Tabel 2 Drag force coefficient at immersion depth of 6 cm

Hole diameter	Cd at each blade angle position		
	0^0	15^0	30^0
0.8 cm	1.31	1.28	1.15
1.2 cm	1.21	1.18	1.03
1.6 cm	1.15	1.10	1.00

At immersion depth of 8 cm, the smallest drag coefficient was 0.80 which occurred at hole diameter 1.6 cm and 30^0 blade angle position. The highest drag force coefficient was 1.07 which occurred at diameter hole 0.8 cm and angle position of 0^0 as shown in Table 3.

Tabel 3 Drag force coefficient at immersion depth of 8 cm

Hole diameter	Cd at each blade angle position		
	0^0	15^0	30^0
0.8 cm	1.07	1.02	0.87
1.2 cm	0.95	0.93	0.83
1.6 cm	0.91	0.91	0.80

Different blade geometry and immersion depth resulted drag force coefficient ranging between 0.8 -1.63. This indicated that geometry significantly affected drag force coefficient as previously mentioned by Munson *et al.* (2006). Drag force coefficient was decreasing along with the increasing blade angle and increasing size of hole diameter.

4.3 Velocity Contour

Fluid velocity contour as produced by different wheel speed at same diameter hole is shown in Figure 12.

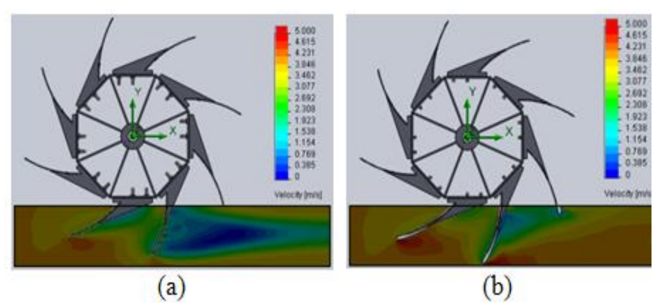

Figure 12. Fluid velocity contour at diameter hole and blade angle of (a) 0.8 cm and 0^0 (b) 1.2 cm and 0^0

Meanwhile, fluid velocity contour at different angle is shown in Figure 13 and 14.

International Journal of Scientific & Engineering Research Volume 6, Issue 2, February-2015
ISSN 2229-5518

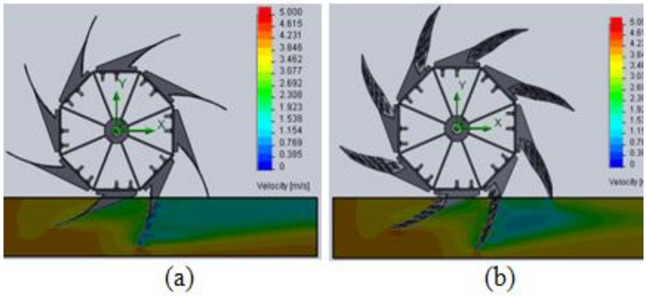

Figure 13. Fluid velocity contour at hole diameter and blade angle of (a) 1.6 cm and 0^0 (b) 1.6 cm and 15^0

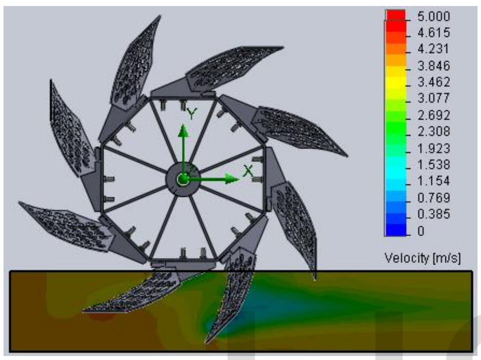

Figure 14. Fluid velocity contour at hole diameter and blade angle of 1.6 cm and 30^0

Blade incoming flow pattern showed slight similar pattern at every blade experiments. Blade out coming flow pattern showed that design using diameter hole 1.6 cm and angle 30^0 had better performance. It was indicated by higher velocity in which the velocity was also more uniform.

5 CONCLUSION

The highest torque was 57.85 Nm which occurred at 8 cm immersion depth with 0.8 cm hole diameter and blade angle of 0^0 at wheel speed of 154 rpm. The lowest torque was 12.48 Nm which occurred at immersion depth of 4 cm with hole diameter of 1.6 cm and 30^0 blade angle position at wheel speed of 115 rpm.

Average torque reduction at blade angle 15^0 was 6.73% and at blade angle 30^0 was 22.27%. Average torque reduction which produced by different hole diameter from 0.8 cm to 1.2 cm was 9.06% and 0.8 cm to 1.6 cm was 12.31% respectively.

Blade incoming flow pattern showed slight similar pattern at every blade experiments. Blade out coming flow pattern showed that design using hole diameter of 1.6 cm and angle position of 30^0 had better performance.

The smallest drag force coefficient was 0.80 which occurred at hole diameter of 1.6 cm, 30^0 blade angle, and immersion depth of 8 cm. The highest drag force coefficient was 1.63 which occurred at hole diameter of 0.8 cm, 0^0 blade angle and immersion depth of 4 cm.

The most appropriate wheel aerator was indicated by the lowest torque requirement which found at hole diameter of 1.6 cm, blade angle position of 30^0 and immersed up to 4 cm depth.

REFERENCE

[1] Laksitanonta S, Singh S, and Singh G, A review of aerators and aeration practices in Thai Aquaculture,"*Agricultural Mechanization in Asia, Africa and Latin America* 34 (4):64-71. 2003.

[2] Moore JM and Boyd CE," Design of small paddle wheel aerators," *Aquac Eng* 11:55-69. 1992.

[3] Romaire RP and Merry GE," Effect of paddle wheel aeration on water quality in crawfish pond," *Appl Aquac* 19(3):61-75. 2007.

[4] Peterson EL and Walker MB," Effect of speed on Taiwanese paddelwheel aeration," *Aquac Eng* 26:129-147. 2002.

[5] Moulick S, Mal BC, and Bandyopadhyay," Prediction of aeration performance of paddle wheel aerators," *Aquac Eng* 25:217-237. 2002.

[6] Wyban JA, Pruder GD, and Leber KM," Paddle wheel effect on shrimp growth, production and crop value in commercial earthen ponds," *J World Aquac Soc* 20:18-23. 1989.

[7] Bhuyar LB, Thakre SB, and Ingole NW,"Design characteristics of curved blade aerator w.r.t. aeration efficiency and overall oxygen transfer coefficient and comparison with *CFD* modeling," *International Journal of Engineering,Science and Technology* 1: 1-15. 2009.

[8] Boyd CE,"Pond water aeration systems," *Aquac Eng* 18:9-40. 1998.

[9] Munson, Young, and Okiishi," Fundamentals of fluid mechanics'" USA : John Wiley & Sons, Inc. 518-538, 2006.