JJMIE

Volume 10 Number 3, September.2016
ISSN 1995-6665
Pages 211-214

Jordan Journal of Mechanical and Industrial Engineering

Improving Mixing in Water Aeration Tanks Using Innovative Self-Powered Mixer and Power Reclamation from Aeration Tank

Ammar A. T. Alkhalidi [a], Patrick Bryar [b], Ryo S. Amano [b]

[a] *Energy Engineering Department - German Jordanian University*

[b] *Department of Mechanical Engineering - University of Wisconsin-Milwaukee*

Received July, 21, 2016 *Accepted August, 25, 2016*

Abstract

The primary objective of the present paper is to increase the Standard Oxygen Transfer Efficiency (SOTE) in aeration tank. To achieve this without increasing the power required to pump air into aeration tanks, a mixer and turbine blades were added to the regular fine bubble aeration diffuser. The turbine blade extracts power from the moving water current and transfers this power to the mixer at the top of the diffuser. A support structure was mounted above the air to connect the turbine blade and the mixer on one shaft. Furthermore, an electrical generator was connected to the shaft to extract surplus energy from the system at high flow rates. Results showed that the mixer powered by the turbine blade extracted power induce less oxygenated water into the core of the bubble column without using additional energy. Thus, this system can lead to a more efficient distribution of oxygen within the water tank. Furthermore, it was found that the turbine blade captured more energy than needed by the mixer, the excess energy was collected using electrical generator. Results showed that self-powered mixer increase the SOTE up to 25%. At the same time 11% power used in air pumping can be reclaimed using the electrical generator at high flow rates.

© 2016 Jordan Journal of Mechanical and Industrial Engineering. All rights reserved

Keywords: Wastewater Treatement, SOTE, Aeration Tank Mixing, Power Reclemation .

Nomenclature

COD	chemical oxygen demand.
SOTE	standard oxygen transfer efficiency.
RPM	rotations per minute.
SS2	Silver Series 2 commercial diffuser commonly used in aeration industry.
S-N	Sharp Nub membrane invented by [10]
PIV	particle image velocimetry.

1. Introduction

Wastewater treatment facilities strive to increase the efficiency of the process of recycling water to be reused. The aeration process, introduction of pressurized air to collected water through diffusers located at the bottom of the containing tank, consumes 50%-70% of the financial cost invoked within a wastewater purification operation [1]. Aeration process efficiency depends on several factors such as the air mass flow rate, depth of diffuser submergence, and the nature of the contents in the wastewater [2].

Water oxygenation process was investigated by Pankhania *et al.* [3] in a laboratory scale membrane aeration bioreactor (MABR) with a void volume of 1.35 litters for its ability to treat synthetic wastewater. DeGuzman [4] invented an apparatus for mixing gas and liquid. Levitsky *et al*. [5] studied the water oxygenation in an experimental aerator with different air/water interaction patterns.

New innovative way to improve mixing in the aeration tank without using extra power was investigated by Alkhalidi and Amano [6]; they used a new innovative air injection method to agitation water and air bubble dispersion; hence, the improved OTE in the aeration basin without extra power depletion. Hudnell *et al.* [7] investigated improving wastewater mixing and oxygenation efficiency with solar-powered circulation.

Bubbles behavior under water was investigated by Dani *et al.'s* work [8]. A trail of oxygenated water was observed when air bubbles travel upwards in water, as shown in Fig1.

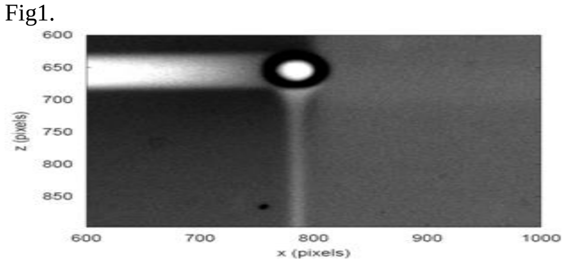

Figure 1. Trail of oxygen behind an air bubble moving upward [8].

* Corresponding author e-mail: .

Based on the results found by Dani *et al*. [8] when subsequent bubbles travel upwards through the wake of the first bubble, they travel on the same highly oxygenated path. This decreases the effectiveness of the bubble oxygenation due to the reduction in the air concentration gradient between inside and outside the bubble.

The driving force of the aeration process is the difference in oxygen concentration levels that exists inside and outside of the bubble. In the present work, a new innovative method of mixing that induces less oxygenated water into the core of the bubble column to overcome the problem of bubbles traveling on the same oxygenated path, hence the improved oxygenation process.

2. Experimental Observation Setup

The observation tank consists of a clear flat panel plexi-glass, 0.9m x 0.9m x 1.2m. This tank was used to mimic the aeration tank in wastewater treatment plant where standard PVC air diffusers 0.23m (9 Inch) are installed at the bottom. The setup was equipped with an accurate pressure regulator flow meter and pressure gages to control the experimental conditions precisely. Bubbles velocity was measured by particle image velocimetry (PIV).

During the experiment, it was observed that when air is allowed through the diffusers installed at the bottom of the aeration tank, it developed a water bubble current within the tank. This current is called 'bubble column' that was created by buoyancy force while driving bubbles toward the water surface. Figure 2 illustrates the currents and the bubble column within the confines of visualization tank used in this work.

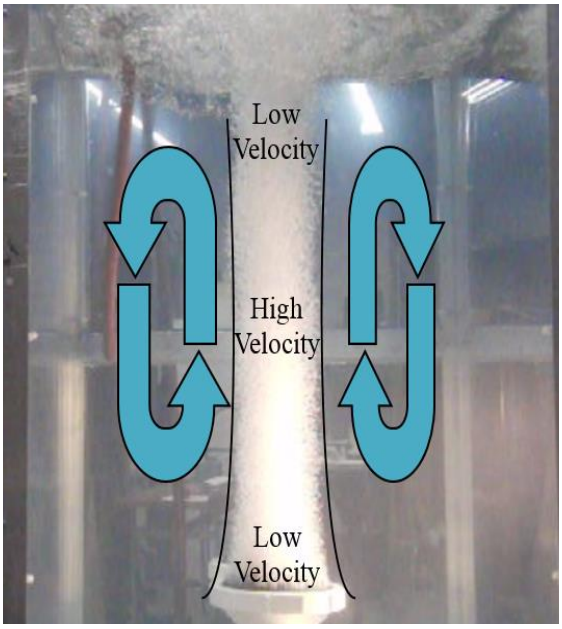

Figure 2. Bubble column, collimation of air bubbles as the progress to the surface of the water. Vertical black lines illustrate the uniformity of the column. Teal arrows illustrate the flow of the water current

The bubbles' velocity was measured using PIV at different heights (0, 100, 200, 300, 400 and 500 mm above the membrane) for different flow rates. Results are shown in Fig. 3.

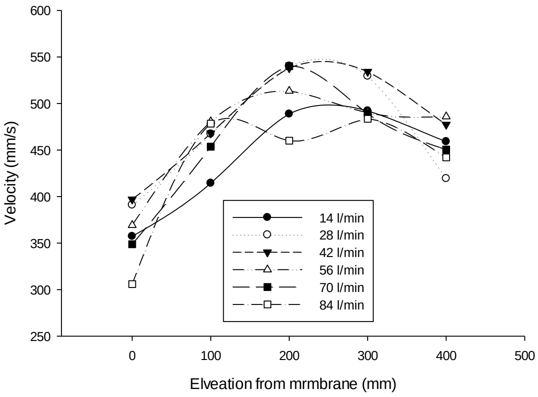

Figure 3. water column velocity at different height from membrane and at different flow rates

The results presented in Fig. 3 show that the maximum velocity location is between 200 mm and 300 mm above the membrane. In addition, the minimum velocity occurs right above the membrane.

Both the water current showed in Fig. 2 and the velocity profile showed in Fig. 3 depict that high kinetic energy exists in the middle of the of the bubble column and low energy at both ends of the column. Based on that, a new idea emerged to install a propeller (Turbine) to extract power from the high velocity location in the water column. This extracted power will be used to operate a mixer at the top of the membrane (low velocity region) to induce the mixing in that region. The mixing will drive the less oxygenated wastewater into the water column. Therefore, the oxygen concentration difference between inside and outside the air bubble will increase and, as a result, the SOTE will increase.

A supporting structure, shown in Fig. 4, was designed and built to hold the blade in place. Friction between the rod that holds the propeller and the stabilizers was assumed negligible due to lubrication from the water present in the tank.

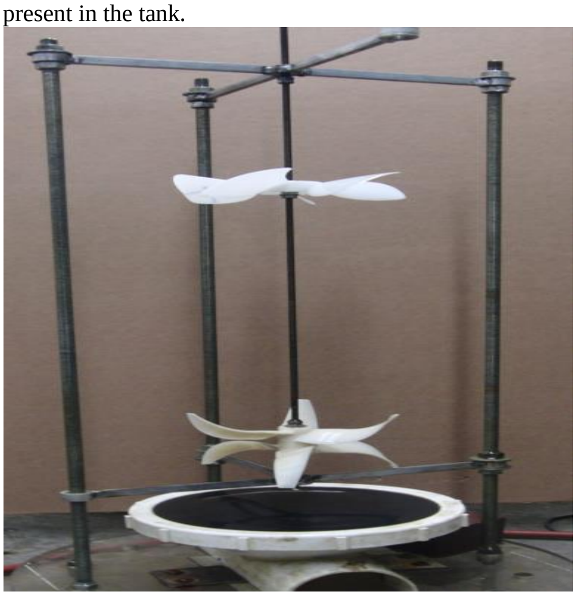

Figure 4. Supporting structure illustration

The blade installed to extract the power in the middle of the bubble column is a household fan blade with 0.178m diameter.

The mixer installed at the bottom is a costume-made with 0.178m diameter. The self-powered mixer airfoil design assists the middle blade by extracting additional energy from water stream. Mixer blades are twisted upwards for the top blade and downwards for the bottom blade to mix the bubble column. The design of the self-powered mixer enables it to mix the water near the diffuser with small external energy. The mixer, shown in Fig. 5, was built on a rapid prototyping machine and implemented in testing rig for testing.

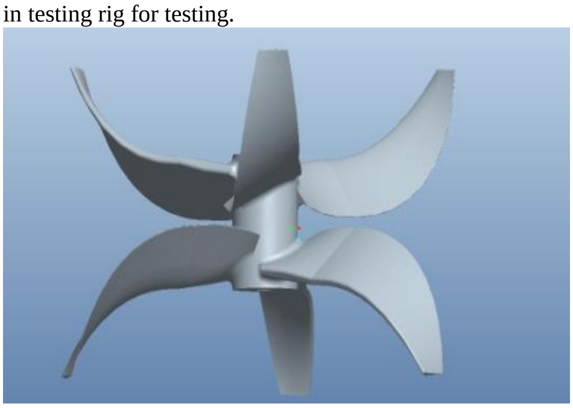

Figure 5. Illustration of the dual blade mixing system.

Test tank and self-powered mixer were built according to the design discussed above. Tests were conducted to investigate the effect of mixing at the top of the membrane on the SOTE.

3. Results

A power generation analysis, based upon resistive load, was conducted by the use of generic generator. The generator was chosen based on its ability to generate high power under a low RPM. This generator was connected directly to the shaft containing the self-powered mixer and the additional blade. Additionally, a 2.5-100 ohm potentiometer was connected in series with this generator. Lastly, a data logging and a generic ohmmeter were connected to the potentiometer in parallel.

For the purpose of the power analysis, the resistive load was measured at intervals from 5 ohms to 95 ohms at increments of 10 ohms. At each iteration, voltage was measured between 850 and 1000 times, and the maximum value was used to determine the peak power generation of the system.

This process was repeated for the airflow rates from 14 l/min to 84 l/min and was varied using 14 l/min intervals. The results from this analysis can be seen in Fig. 6.

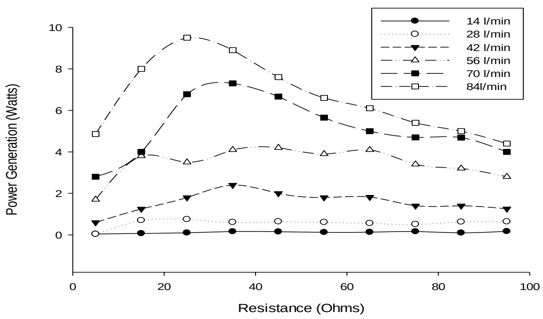

Figure 6. A comparison between power generation and resistive load at different flow rates.

In order to render this information better, a comparison between data generated from newly proposed system and the power used by a generic pond air blower was utilized. It was determined that the blower system was a good comparison point since it consumes all of the power within the water aeration phase of wastewater treatment [9]. A generic pond air blower was chosen based on the head pressures and designed flow rates. Both attributions are comparable to the proposed system within the confinement of the experimental tank. A comparison of the results is shown in Fig. 7.

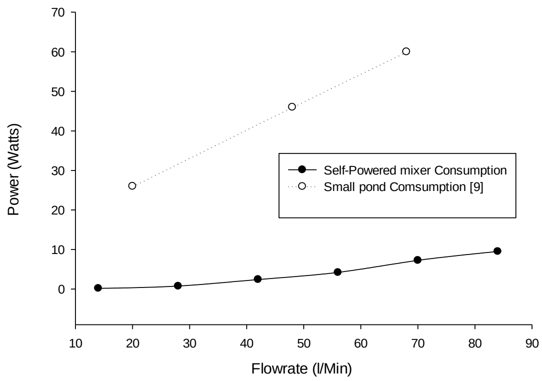

Figure 7. A comparison of power reclamation from self-powered mixer and power requirements of a generic blower small pond consumption [9].

Figure 7 shows that the electrical power consumed by small ponds for air pumping could be reduced up to 80% by installing the new proposed system. One advantage of the proposed system is that it can be added to any existing fine bubble aeration system.

Finally, an SOTE analysis was conducted in compliance with clean water act [10]. SOTE was tested though the use of three dissolved oxygen probes affixed within a cylindrical testing tank 750 L in size to eliminate dead zones in the tank. The self-powered system was tested using two membranes, commercially standard membrane SS2 and the Sharp Nub membrane. Both membranes were tested twice with and without the attachment of the electrical generator.

The Sharp Nub membrane is a laboratory membrane invented by Amano and alkhalidi [11]. It uses a nozzle that forces bubbles to split into three smaller bubbles. Thus, it produces much smaller bubbles than the SS2 membrane. The results are shown in Fig. 8.

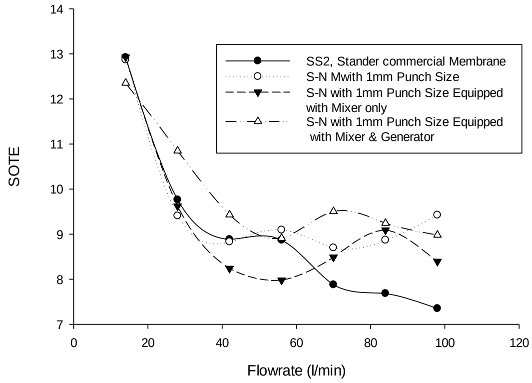

Figure 8. Graphical illustration of resulting SOTE results for sharp-Nub membrane and compared to SS2 rubber diffuser.

The results presented in Fig. 8 indicate an increase in SOTE, at high flow rates, after 60 l/min, for both cases of using the self-powered mixer only and using the self-powered mixer attached to the generator. It should be noted that a resistive load was maintained at 40 ohms, that is, almost at the highest power generation point as shown in Fig. 6.

4. Conclusions

Bubble column velocity was investigated using PIV. It was found that the velocity varies with the depth from the water surface. In the present paper, energy was extracted from a high velocity location in the water column and reapplied at the low velocity regime to improve SOTE distribution. This was achieved by utilizing an innovative self-powered mixer device located right above the membrane combined with turbine blade at the highest velocity location.

The use of the self-powered mixer indicated an increase in SOTE of approximately 25% at high flow rates in the best cases using the Sharp Nub diffuser system. Moreover, results indicate a significant ability to reclaim power, at higher airflow rates. This power reclamation was able to yield gains up to 11%.

References

[1] American Society of Civil Engineering, “A Standard for the Measurement of Oxygen Transfer in Clean Water", 1984, New York, N.Y.

[2] A. Alkhalidi, & R. Amano, Factors Affecting Fine Bubble Creation and Bubble Size for Activated Sludge. Water and Environmental Journal, vol. 29. No 1, 2015, pp. 105-113.

[3] M. Pankhania, K. Brindle, and T. Stephenson, Membrane aeration bioreactors for wastewater treatment: completely mixed and plug-flow operation, Chemical Engineering Journal, Vol. 73, No. 2, 1999, pp. 131–136.

[4] V. DeGuzman, Apparatus for mixing gas and liquid, 1994, Patent number US 5376311 A

[5] S. Levitsky, L. Grinis, J. Haddad, and M. Levitsky, Water oxygenation in an experimental aerator with different air/water interaction patterns. HAIT Journal of Science and Engineering B, Vol. 2, No. 1-2, 2005, pp. 242-253.

[6] A. Alkhalidi, H. Al Ba’ba’a and R. Amano, Wave generation in Subsurface Aeration System: A New Approach to Enhance Mixing in Aeration Tank in Wastewater Treatment. Desalination and Water Treatment, 2016, DOI:10.1080/19443994.2016.1172263.

[7] H. Hudnell, D. Green, R. Vien, S. Butler, G. Rahe, B. Richards, and J. Bleth, Clean Technologies and Environmental Policy, Vol. 13, No. 5, 2011, pp 731-742.

[8] A. Dani, F. Guiraud, A. Cockx, "Local measurement of oxygen transfer around a single bubble by planar laser-induced fluorescence", Chemical Engineering Science, Vol. 62, No. 24, 2007, pp. 7245-7252.

[9] C. Tucker, “Pond Aeration", SRAC publication, September 2005.

[10] ASCE, Front Matter and Software, Measurement of Oxygen Transfer in Clean Water: ANSI/ASCE 2-91, 1993, pp. i–x, doi: 10.1061/9780872628854.fm.

[11] Amano R. and Alkhalidi A., Membrane for Air Diffuser, 2013, Patent number US 20130099401 A1.