Computational Studies of Confined Submerge Fan to Circulate and Oxygenate Hypolimnetic Layer in Hydro Power Reservoirs

Muhammad Umar Mushtaq[1], Khairuddin Sanaullah[1], Andrew Ragai Henry Rigit[2], Afrasyab Khan[2] and Harunal Rejan Ramji[1]
[1]*Department of Chemical and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Malaysia.*
[2]*Department of Mechanical and Manufacturing Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Malaysia.*
muhammadumarmushtaq@gmail.com

***Abstract*—The oxygen level is deficient at the depth of the lakes or reservoirs due to thermal stratification. Due to deficient oxygen level at the bottom of thermal stratified lakes, the reduction reactions occur that form hydrogen sulphide, iron, phosphorous and other compounds which are harmful to the water quality, fish life as well as dam or reservoir structures and other species. Hypolimnetic aeration and oxygenation systems can be used for this purpose to prevent the formation of harmful substances. A prototype design of submerged fan will be used to penetrate at maximum depth of the lakes or reservoirs and find the velocity of the submerged fan through CFD simulations.**

***Index Terms*—Thermal Stratification; Deficient Oxygen; Aeration; Submerged Fan; CFD Simulations.**

I. Introduction

The preservation of freshwater quality is nowadays becoming a very important issue because of the increasing water demand for last few decades. The threatening problem with the quality of fresh reservoir/dam water for countries in tropical regions is eutrophication. Eutrophication is due to the gathering of the excessive richness of nutrients in a lake or other body of water, which promotes the dense growth of plant life and death of animal life (e.g. bloom, phytoplankton) from lack of oxygen in the bottom layer. During summer, hot temperature causes a stratification process dividing the water volume during a large period of the year. The thermal stratification is a change in the temperature at different depths in the lake and is due to the change in water's density with temperature. It consists of three layers. Epilimnion is the top-most layer in a thermally stratified lake. It is warmer and typically has a higher pH and dissolved oxygen concentration than the hypolimnion. Thermocline is a thin but distinct layer in a large body of fluid (e.g. water, such as an ocean or lake, or air, such as an atmosphere). Hypolimnion is the dense, bottom layer of water in a thermally stratified lake. It is the layer that lies below the thermocline. The hypolimnion may be much warmer in lakes at warmer latitudes. In the hypolimnion of productive (productive lakes means measurements of dissolved oxygen and temperature) lakes the sedimentation of organic matter from the surface water is extensive. Algae and other suspended particles are abundant, light penetration through the water column to the hypolimnion are limited and photosynthesis cannot occur. Under these conditions, the bottom sediments during the decomposition of the organic matter greatly exceed the oxygen produced. This results in depletion and in some cases a complete absence of dissolved oxygen in the hypolimnion layer. Due to the deficient oxygen at the bottom of the lakes or reservoirs causes the reduction processes, which lead to the formation of hydrogen sulphide, iron, manganese and phosphorous and these are harmful to the aquatic life e.g. salmon, roach, carp, trout, turtles, etc. and the water quality which can be harmful if being used for drinking and cooking purposed without treatment.

II. Background

According to Singleton [1], there are three primary devices that include airlift aerator, speece cone, and bubble plume diffuser which can be appropriately proposed for restoring hypolimnetic aeration as well as oxygenation systems to dissolve oxygen in the bodies of water in order to preserve stratification. Further, the initial aeration systems were used to have mechanical agitation of water, directly pumped on the surface of a lake from the hypolimnion into a splash basin as reported in the study [2].

Moreover, there are airlift devices which can be used for hypolimnetic aeration; similarly, partial-lift systems can be operated to inject compressed air in the vicinity of the base of the hypolimnion. The mixture of air-water can travel through the vertical tube at the specified depth in the lake. The remaining gas bubbles can be vented to the atmosphere through a pipe to the surface. However, the oxygenated water is revisited towards the hypolimnion; whereas, full lift systems can be considered as the same excluding air-water mixture [3] which can be arisen to the surface prior to releasing the residual gas bubbles [4].

Dr. Richard Speece invented [5]-[7] speece cone device which is comprised on the conical chamber based on large diameter of the reservoir at the bottom or the base and in which water is used from the top of the cone; whereas, the cross-sectional area has been considered as the smallest by means of a submersible pump flows downward.

Many studies including [8]-[9] reported that the most hydrodynamically complex device is used to be called as the bubble-plume diffuser; similarly, air or oxygen bubbles are called into the base of the reservoir from an unconfined bubble diffuser. According to Mobley, the diffuser can be divided into two different types including either large circular diffuser or a long rectangular diffuser [10]. However, the induced water velocity is considered as the dependent on the amount of gas which is introduced as per unit volume in terms of water as well as the thermal stratification in the reservoir. The oxygen is used to be dissolved from the bubbles as the plume water rises; however, traveling with the water continues till the plume loses its vertical momentum in addition to the velocity; therefore, the oxygenated water used to fall back to the layer of neutral buoyancy as mentioned in previous studies [11].

A floating water treatment device for biological treatment of water in a body of water, the device comprising, a submerged biomass carrying system having at least one biomass carrying element, a water aeration device adapted to aerate the water in the body of water in the vicinity of the biomass carrying system, and flotation system adapted to float on the surface of the body of water and to support the submerged biomass-carrying system and water aeration device from totally submerging into the body of water. [12].

An aerator is used for inducing air flow below the surface of a liquid. The aerator includes a motor having a drive shaft. A propeller is operably connected to the drive shaft of the motor and a blower is operably connected to the motor. The aerator further includes an air flow path that has an inlet and an outlet, with the inlet connected to the blower and the outlet located near the propeller. The blower and the propeller rotate at different speeds. [13]. Further, Brunello [14] reported that a marine drive system has been located at the transom of a boat comprising a partially submerged propeller; a forward opened shroud can be positioned above the propeller for each propeller to define it and the water level; a channel extends longitudinally with the propeller and a cross-section whose area is decreased from the transom.

The water quality of source water reservoirs can be improved by extending non-submerged as well as submerged water lifting aerators. This study is done to explore the algae inhibition effects of submerged along with non-submerged water lifting aerators under various hydrological and operating conditions [15]. Further, this is used to analyse the energy dissipation of hydraulic jump by the flow pattern's evolvement of the stilling basin with step down floor. Jet hydraulic theory and velocity distribution formulas are drawn to analyse the wall jet region of stilling basin [16].

The performance of a pilot scale down flow bubble contact hypolimnetic aerator as well as Speece cone examining the oxygen transfer coefficient, standard oxygen transfer rate, standard aeration efficiency, and standard oxygen transfer efficiency in order to determine the effect of inlet water velocity as well as ratio of gas flow rate to water flow rate of hypolimnetic aerator and Speece cone [17].

Earlier industrial applications mostly relied on airlift aerators, which have been designed on empirical formulations and same has been true for bubble plume methods. However, bubble plume based models cannot account for stratification or gas transfer accurately. Moreover, they require huge compressors and contain several limitations to enrich the large body of water with oxygen. This design will not require any compressor because the purpose of grooves insert in the fan is to avoid the load on the motor and provide minimum external energy.

The present proposed research will focus on the design of confined submerged fan with the help of ANSYS Fluent software. Oxygenation of the hypolimnetic layer by the application of prototype mechanical aeration method will reduce significantly the reduction processes, which are responsible for the formation of different harmful species like hydrogen sulphide, iron, phosphorous etc.

III. Equipment And Methods

A. Computational Schemes and Confined Submerged Fan Design

Figure 1 shows schematic of the experimental facility used for measurements illustrating the downward flow of top layer water right to the bottom of the column using a submerged fan. The walls of the column will be made transparent to aid flow visualisation and pressure velocity measurements (Pitot tube used to measure the pressure velocity and pressure strain rate). The dimensions of the column are 70 cm in length and 2 cm diameter. The submerged fan has three stages having 9 wings. Each stage has 3 wings. The purpose of three stages is to push the water downwards with strong force with help in deep penetration. When the water strikes with the first stage of a submerged fan, the rest of the water strikes with a second and third stage which provide strong force or movement to water same like in air jets to penetrate downwards. The specialty of each wing is inserted with a number of thin and cone shape like grooves on the bottom surface of the submerged fan. The length of each wing is 0.5 cm. The purpose of grooves is to reduce the drag and when water strikes the empty slots (grooves) it penetrates more and the load on the motor will reduce. The fan wings are tilled at angle 300. The construction material selected for the submerged fan will be steel.

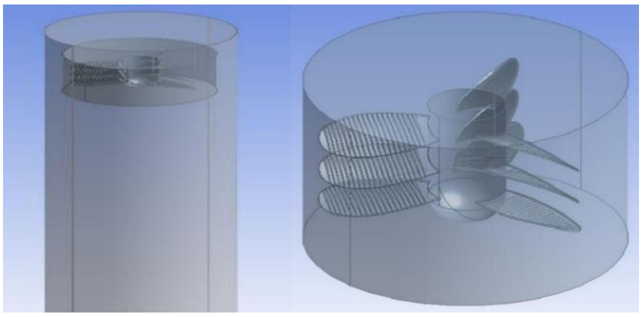

Figure 1: Submerged fan with transparent column

This study initiates with the computational aspect of the project and thus using the workbench to generate geometrical sketches of a submerged fan exhibiting close views of wings carrying grooves on them as shown in Figure 2. The dimensions of the submerged fan chosen for simulation are 1.5cm diameter and 1 cm height. The CFD commercial code ANSYS FLUENT 14.0 has been used to simulate the calculations within this geometry. The code has been relied on the finite volume method to solve the Navier-Stokes equations. The computations have been based on the control volume discretization scheme along with the segregated solvers and default parameter settings of FLUENT, are shown in Table 1.

Table 1
Parameters setup in FLUENT

Under Relaxation Factors Equation	Value	Discretization Equation	Value
Pressure (Pa)	0.3	Pressure	Standard
Density (kg/m^3)	1	Pressure Velocity Coupling	Simple
Body Forces (N)	1	Momentum	First Order Upwind
Momentum (N.s)	0.7	Turbulence Kinetic Energy	First Order Upwind
Turbulence Kinetic Energy (J)	0.8	Turbulence Dissipation Rate	First Order Upwind
Turbulence Dissipation Rate (m^2/s)	0.8		
Turbulence Viscosity (Pa. s)	1		

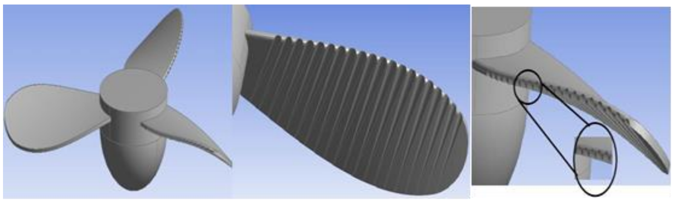

Figure 2: Prototype design of the submerged fan

The meshing detail of submerged fan is given in Table 2.

Table 2
The size information of grid

Relevance Center	Nodes	Elements	Mesh Matric
Fine	268486	1385433	Skewness

IV. Results And Discussion

The results for calculating the velocity of the confined submerged fan by using CFD model. Based on the numerical simulation, detailed discussion and possibly improved approach were proposed. The velocity profile has been measured in the volume cylinder which dimensions are 2 cm diameter and 70 cm height. Figure 3 represents simulate contour in the cylinder. At the top of the submerged fan, the velocity is lower than the upper right surface of the submerged fan. At the corners of the cylinder, the velocity is zero. Below the submerged fan the velocity is greater than the top of the submerged fan and with the same velocity, it penetrates downwards at 68 cm depth. The legend shows the different values of the velocity. The velocity of the submerged fan changes with a time interval. At the beginning, the velocity is increased than with the passage of time its decrease. It shows the behavior of the submerged fan which penetrates the oxygen in the depth layer of lakes and reservoirs. Streamlines represent the direction of flow. These lines represent the dispersion of fluid either radial or axial. The purpose of grooves is penetrating more downwards. The groove opening surface is smooth and water is a strike to the empty slots of grooves it penetrates more and less drag [18]. Grooves shape can be modified either circular or triangle both help to circulate the oxygen in the deep layer of lakes and reservoirs. Change the diameter, length, thickness and space between two grooves with the passage of time to achieve more penetration to circulate the oxygen in the bottom layer of the lakes and reservoirs.

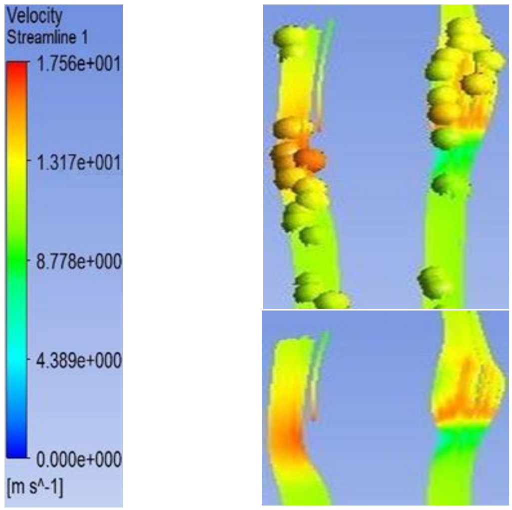

Figure 3: Velocity profile of submerged fan

V. Conclusion

Application of confined submerged fan will surely improve the aquatic life in terms of provision of abundant oxygen to the bottom layer of the lake or reservoirs. This will initiate the economic activities and assist in creating a sustainable fishing culture in Sarawak and will thus boost its environment and water resources. In addition, it will present a novel idea to the learned and research communities globally on the design of a submerged fan.

References

[1] V. L. Singleton and J. C. Little, "Designing Hypolimnetic Aeration and Oxygenation Systems − A Review," *Environmental Science & Technology*, vol. 40, no. 24, pp. 7512–7520, 2006.
[2] P. Mercier, Aeration of Lake Bret. *Monastbull Schwiez. Ver. Gas. Wasser-Fachm*, vol. 29, p. 25, 1949.
[3] M. W. Beutel and A. J. Horne, "A Review of the Effects of Hypolimnetic Oxygenation on Lake and Reservoir Water Quality," *Lake and Reservoir Management*, vol. 15, no. 4, pp. 285–297, 1999.
[4] R. W. Kortmann, "Oligotrophication of Lake Shenipsit by Layer Aeration," *Lake and Reservoir Management*, vol. 9, no. 1, pp. 94–97, 1994.
[5] R. E. Speece, F. Rayyan and G. Murfee, "Applications of commercial oxygen to water and wastewater systems," *Center for Research in Water Resources*, pp. 342–361, 1973.
[6] J. O. Sanders Jr., Camanche, "Hypolimnetic oxygenation demonstration project," *East Bay Municipal Utility District, Oakland, California*, 1994.
[7] J. A. Thomas, W. H. Funk, B. C. Moore, and W. W. Budd, "Short Term Changes In Newman Lake Following Hypolimnetic Aeration With The Speece Cone," *Lake and Reservoir Management*, vol. 9, no. 1, pp. 111–113, 1994.
[8] G. D. Cooke and R. E. Carlson, "Reservoir Management for Water Quality and THM Precursor Control," *AWWA Research Foundation*, p. 387, 1989.
[9] A. Wüest, N. H. Brooks, and D. M. Imboden, "Bubble plume modeling for lake restoration," *Water Resources Research*, vol. 28, no. 12, pp. 3235–3250, 1992.
[10] M. H. Mobley, "TVA Reservoir Aeration Diffuser System," *TVA Technical Paper*, vol. 3, pp. 2010-2019, 1997.
[11] F. Rayyan and R. E. Speece, "Hydrodynamics of bubble plumes and oxygen absorption in stratified impoundments," *Prog. Wat. Tech.*, vol. 9, pp. 129-142, 1977.
[12] J. Gavrieli, P. Hascalovici, and E. Hascalovici, "Floating water treatment device," *U.S. Patent Application No. 13/041,460*, 2011.
[13] P. S. Gross and C. Petrescu, "Turbocharged aerator," *U.S. Patent No.7, 048, 260*, 2006.
[14] B. Acampora, "Marine drive system with partially submerged propeller," *U.S. Patent No. 7, 993, 173*, 2011.
[15] X. Sun, X. Li, M. Zhang, T. Huang, W. Liu, "Comparison of water-

lifting aerator type for algae inhibition in stratified source water reservoirs," *Ecological Engineering*, vol. 73, pp. 624-634, 2014.

[16] Q. Zhang, J. R. Zhang, and Y. Zhou, "Study on Flow Characteristics in Step-Down Floor for Energy Dissipation of Hydraulic Jump," *South-to-North Water Transfers and Water Science & Technology*, vol. 3, p. 029, 2008.

[17] K. Ashley, K. Fattah, D. Mavinic, and S. Kosari, "Analysis of Design Factors Influencing the Oxygen Transfer of a Pilot-Scale Speece Cone Hypolimnetic Aerator," *Journal of Environmental Engineering*, vol. 140, no. 3, p. 04013011, 2014.

[18] Z. H. Sun and T. T. Shi, "Drag Reduction Study on Rotors with Triangle Groove Surface," *Energy and Environment Technology*, vol. 1, 2009. IEEE.