Engineering Science and Technology, an International Journal 21 (2018) 255–260

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Full Length Article

Study on oxygen transfer by solid jet aerator with multiple openings

B.K. Shukla [a,*], A. Goel [b]

[a] Lovely Professional University, Phagwara, Punjab 144411, India
[b] National Institute of Technology Kurukshetra, Haryana 136119, India

ARTICLE INFO

Article history:
Received 8 June 2017
Revised 22 January 2018
Accepted 9 March 2018
Available online 19 March 2018

Keywords:
Plunging jet
Jet aerator
Oxygen transfer
Aeration
Dissolved oxygen

ABSTRACT

In the current study, two different sets of solid jet aerators having area of openings equal to 594.96 mm^2 and 246.30 mm^2 with rectangular nozzles having rounded ends were studied. Each set consisted of aerators having one, two, four and eight openings. The oxygenation performance of every model was studied for five different discharges of 1.11 *l/s*, 2.10 *l/s*, 2.96 *l/s*, 3.83 *l/s* and 4.69 *l/s*. At low discharges, the aerator having lesser number of openings demonstrated more oxygen-transfer efficiency whereas at higher discharges, the aerator having more number of openings yielded more oxygenation-efficiency. Maximum value of oxygen-transfer efficiency of 21.53 kg-O_2/kW-hr was obtained for the discharge of 1.11 *l/s* for single nozzle aerator; however the maximum oxygen-transfer factor of $2.0 \times 10^{-2}\ s^{-1}$ was obtained at discharge of 4.69 *l/s* for aerator having eight numbers of openings having area of 594.96 mm^2. On the other hand, maximum oxygen transfer efficiency of 10.93 kg-O_2/kW-hr was demonstrated by aerator with single opening at a discharge of 1.11 *l/s* and maximum oxygen transfer factor of $7.83 \times 10^{-3}\ s^{-1}$ was obtained from aerator with eight openings at a discharge of 4.69 *l/s* corresponding to set of aerators with area of openings equal to 246.30 mm^2. Multiple non-linear regression modelling was applied to predict oxygen transfer of the aerators for different combinations of input parameters. At the end, the models were compared with conventional methods of aeration and were found to be competitive with traditional devices.

1. Introduction

Aeration is one of the most important steps in the treatment of waste water [16]. Out of the several available methods of aeration, surface jet aerators are considered most economical and efficient method due to make-up of close system, easy in installation and working [21,11,2]. Surface Jet Aerators are easy in design, construction and working without operational difficulties. Solid jet emerging from aerator openings forms a two phase region with large air–water interface when it plunges into water after passing through atmospheric air [14,15,17]. Aerodynamic and hydrodynamic forces come into play between incoming jets of air and water in this region [4,5]. Perfect mixing of air and water can safely be assumed [2] as the design of solid surface jet aerator facilitates closed system [13]. Jet geometry and plunge angle have considerable effect on air entrainment rate into water [1]. As a result of exhaustive studies by many researcher at NIT Kurukshetra [10,9,8,7,18,12,19], it was concluded that the performance of aerator having rectangular shaped openings with rounded edges was much better as compared to aerators with circular, elliptical, rectangular or square shaped openings.

As a result of earlier research works, it was found that discharge, plunge angle, geometry, flow area and number of openings are the factors on which the performance of an aerator depends [20,22]. So far, study of the impact of variation in number of solid jets having rectangular with rounded edges on oxygen transfer efficiency and oxygen transfer factor of rectangular with rounded edge shaped solid jet aerator has not been done. The objective of this work is to study the effect of variation of number of openings of aerator having rectangular with rounded edges and variation of total area of openings on the oxygen transfer (expressed in terms of standard volumetric oxygen transfer co-efficient), the oxygen transfer efficiency w.r.t. discharge and to develop empirical relationship for prediction of these parameters as a result of mathematical modelling of the experimental data.

2. Basic equations to measure oxygen transfer by plunging jet

Perfect air–water mixing is assumed in the case of surface jet as it facilitates make-up of a "closed" system [3,11,2,10,9]. Oxygen

* Corresponding author at: School of Civil Engineering, Lovely Professional University, Phagwara, Punjab 144411, India.
E-mail address: bishnukantshukla@gmail.com (B.K. Shukla).

Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.03.007
2215-0986/

balance equation in the case of a closed system that relates the dissolved oxygen concentration (D.O.) to oxygen mass transfer rate (dC/dt) between air and water can be expressed as in Eq. (1) [2] given below:

$$\frac{dC}{dt} = K_L \frac{A}{V}(C_s - C) \tag{1}$$

where the K_L represents the co-efficient of liquid film of the bulk liquid in the tank; A denotes the air–water interfacial area, V is the volume of the liquid bulk in the tank; C_s denotes the saturation value of the dissolved oxygen concentration in the water at the given temperature, pressure and salinity and C represents the actual concentration of the oxygen at the prevailing conditions. Denoting the term 'A/V' as 'a' (specific surface area) and thus the term outside the parentheses becomes 'K_La', pronounced as volumetric oxygen-transfer factor. Thus Eq. (1) takes the form as in Eq. (2).

$$\frac{dC}{dt} = K_La(C_s - C) \tag{2}$$

By integrating Eq. (2) between the limits $C = C_o$ at $t = 0$ and $C = C_t$ at $t = t$, we get (Eq. (3))

$$K_La = \frac{1}{t}\ln\left[\frac{C_s - C_o}{C_s - C_t}\right] \tag{3}$$

Where, C_o denotes the initial D.O. concentration at the start of the aeration process and C_t, is D.O. concentration at the end of the process. As per the Eq.3, the value of oxygen-transfer factor (K_La) can easily be obtained by measuring the time of aeration and dissolved oxygen concentrations at the start, at the end and at the saturation points. Since, the saturation dissolved oxygen concentration (C_s) and hence the overall dissolved oxygen concentration depend on temperature, K_La needs to be normalized to a standard temperature in order to have uniform basis of comparison. Generally, 20 °C is chosen as standard temperature. The conversion of K_La from different temperatures to standard value can be expressed [6] as given in Eq. (4)

$$K_La_{(20)} = K_La_T \times \theta^{(20-T)} \tag{4}$$

where, $K_L\alpha_{(20)}$ represents the standard oxygen-transfer co-efficient at 20 °C (s^{-1}); T denotes temperature of water (°C); $K_L\alpha_T$ represents oxygen-transfer co-efficient at T°C and θ is a temperature dependent term the value of which can be given as follow:θ = 1.025 for temperature more than or equal to 5 °C and less than 25 °C

θ = 1.028 for temperature more than or equal to 25 °C and less than 35 °C

θ = 1.031 for temperature more than or equal to 35 °C and less than 45 °C

The jet power per unit volume (P/V) in kW/m^3, can be expressed as in Eq. (5) [2] given below:

$$\frac{P}{V} = \frac{1}{2} \times \frac{\rho Q v_j^2}{V} \tag{5}$$

where, V is bulk water volume in the pool (m^3); ρ denotes density of water (kg/m^3); Q represents discharge (m^3/s) and v_j denotes velocity of jet at exit (m/s).

The oxygen-transfer performance of plunging jet is measured in terms of oxygen-transfer efficiency (OTE) that is expressed as shown in Eq.6 [2].

$$OTE = \frac{O_R V}{P} \tag{6}$$

Where OTE is oxygen-transfer efficiency of the plunging jet aerator (kgO_2/kWh); V denotes water bulk volume (l) and O_R represents the rate of oxygen mass transfer (mg/L/h) at 20 °C temperature and one atmospheric pressure. O_R is expressed as given in Eq. (7) [2].

$$O_R = K_La_{(20)} \times 3600 \times C_s^* \tag{7}$$

where, C_s^* represents saturation oxygen concentration of water at 20 °C temperature and one atmospheric pressure.

3. Experimental program

The complete experimental program is explained under the following subheads:

3.1. Experimental Set-up

The experimental set-up mainly consists of a cubical water tank (1m × 1 m×1m), a centrifugal pump (3hp), a flow regulating valve, a hollow plunging jet device (Fig. 2), an Orificemeter, a thermometer and a scale as shown in Fig. 1. The water tank was made of a graduated transparent fibre glass and the water was re-circulated into it by the 3 hp centrifugal pump. The depth of water was kept constant at 600 mm throughout the experiment. The jet length of the plunging jet in air was kept constant at the level of 150 mm throughout the experiment. The discharge of water in re-circulation pipe was varied using flow regulating valve and measured with the help of Orificemeter as shown in Fig. 1. A digital thermometer was used to measure temperature of the water during experimentations. The solid plunging jet device (Fig. 2) was fitted to exit end of recirculation pipe which was centrally located above the tank. Each model of aerator was tested for five different discharges viz., 1.11 L/s, 2.1 L/s, 2.96 L/s, 3.83 L/s and 4.69 L/s and D.O. concentration of water was determined before and after each run of experiment using modified azide method of Winkler's test. For each measurement, test was conducted three times and average of the three results was taken for final consideration.

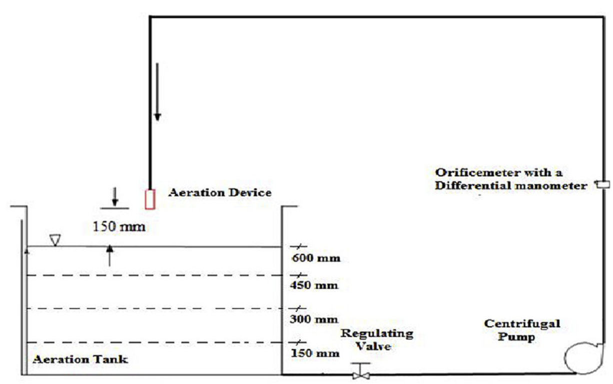

Fig. 1. Experimental set-up.

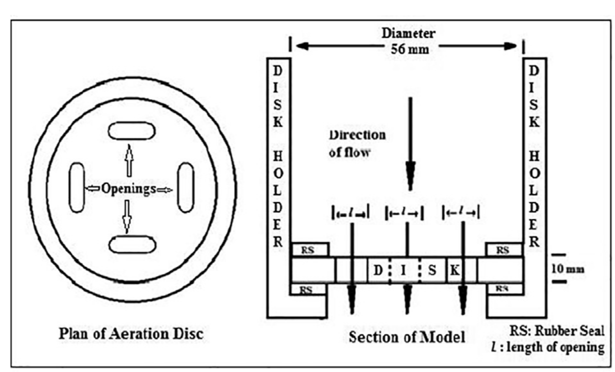

Fig. 2. Solid-plunging jet device.