Journal of Environmental Chemical Engineering 4 (2016) 4565–4573

Contents lists available at ScienceDirect

Journal of Environmental Chemical Engineering

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

Passive aeration of wastewater treated by an anaerobic process—A design approach

Ayman M. El-Zahaby[a,*], Ahmed S. El-Gendy[b]

[a] Environmental Engineering program, The American University in Cairo (AUC), Cairo, Egypt
[b] Department of Construction Engineering, The American University in Cairo (AUC), Cairo, Egypt

ARTICLE INFO

Article history:
Received 28 July 2016
Received in revised form 3 October 2016
Accepted 21 October 2016
Available online 22 October 2016

Keywords:
Anaerobic treatment
Mathematical modelling
Passive aeration
Tray aerator
Wastewater

ABSTRACT

Passive aeration units are units that operate without the need for electric energy. On the contrary to cascade and spray aerators, tray aerators require a much smaller area for their installation. While researching the design of tray aerators, the authors observed a shortage of literature pertaining to the topic. The research objective is to develop a model for the design of tray aerators for the purpose of increasing the dissolved oxygen in wastewater. The analysis focuses on the jetting free falling flow regime. This paper derives a set of equations that estimate the dissolved oxygen concentration in the effluent from the tray aerator system as a function of the flow rate, number of trays, tray area, spacing between trays, number and diameter of holes per tray. Results illustrate that the aeration performance is largely affected by the tray area, number of trays and flow rate while other parameters did not affect the aeration significantly.

1. Introduction

Anaerobic wastewater treatment gained popularity due to its relatively low investment cost, running cost and the possibility of production of biogas, instead of energy consumption in conventional aerobic treatment process. Thus anaerobic wastewater treatment units are capable of sustaining the natural energy resources [1].

One drawback of the anaerobic treatment process is that the anaerobic treatment alone cannot reach the effluent quality that is permissible for the discharge in receiving waterbody. For that reason, a post treatment unit should be installed following the anaerobic unit [2,3]. Thus, in order to promote the practical applications of anaerobic treatment units, various design arrangements that utilize an anaerobic system as a primary treatment and a post treatment aerobic system were studied. Kassab et al. [2] classified those arrangements into two categories; namely sequential anaerobic-suspended growth aerobic systems, and sequential anaerobic-attached growth aerobic systems. Several articles are published proposing the use of attached growth systems as the post treatment aerobic unit, for its low cost [4–7].

For all options of post treatment, water entering the aerobic unit must maintain high Dissolved Oxygen (*DO*) for the unit to operate effectively. This high *DO* shall either be added before the aerobic unit as in the attached growth trickling filter units, or within the unit as in the suspended growth activated sludge systems. This is due to the fact that the aerobic microorganisms need oxygen for their respiration [8]. As the effluent from the anaerobic units has zero *DO* [4], this effluent should be aerated to increase the water *DO* before entering the aerobic unit. Conventional aeration units such as mechanical aerators or diffused aerators require electrical energy input, and their mechanical parts require frequent maintenance and relatively high operating cost. Therefore, there is a need to have a more sustainable, easy to operate and economical option for aeration. These criteria can be met by using passive aeration techniques, which do not require any electrical energy, such as cascade aerators, spray aerators or tray aerators. As both cascade aerators and spray aerators need a large area footprint for their installation [7,9,10], the use of tray aerators offers a more practical option for places where land availability is a constraint.

Tray aerators are aeration devices that rely on the available head in the influent water to lift water at an elevated point right above the distribution tray, from which water flows under gravitational forces over a series of horizontal perforated plates below each other as illustrated in Fig. 1. The tray aerator is generally formed of a number (*N*) of trays arranged vertically underneath each other at a

* Corresponding author.
E-mail addresses: aelzahaby@aucegypt.edu (A.M. El-Zahaby), ahmed.elgendy@aucegypt.edu (A.S. El-Gendy).

http://dx.doi.org/10.1016/j.jece.2016.10.025
2213-3437/

Nomenclature

a	Specific surface area = A/V, [m^2/m^3]
A	Interfacial area, [m^2]
A_j	Cross section area of the water jets, [m^2]
C	Concentration, [mg/L]
Cv	Coefficient of velocity for flow through nozzle, [dimensionless]
C_d	Coefficient of discharge for flow through nozzle, [dimensionless]
d	Hole diameter, [m]
D	Falling water drop/jet diameter, [m]
D_L	Diffusivity of air in water, [m^2/s]
D_j	Mean jet diameter, [m]
g	Acceleration due to gravity [m/s^2] (9.81 m/s^2)
h	Height of water film over tray, [m]
h'	Corrected height of water film over tray, [m]
h_s	Tray side height, [m]
H	Overall system height, [m]
HLR	Hydraulic loading rate = Q/A, [m^3/m^2/s]
i	Number of trays
K_L	Overall liquid mass transfer coefficient, [m^2]
L	Length, [m]
n	Number of holes per tray
n'	Corrected number of holes per tray
N	Total number of trays in the system
Q	Flow rate, [m^3/s]
Q_{hole}	Flow rate per hole, [m^3/s]
S	Surface renewal rate, [1/s]
SP	Spacing between trays, [m]
t	Time, [s]
t_e	Exposure time, [s]
V	Volume, [m^3]
v	Velocity, [m/s]
δ	Film thickness, [m]
ρ	Density, [kg/m^3] (997.2 kg/m3 for water at 24°)
σ	Surface tension, [N/m] (0.073 N/m for water at 24°)
BO	Bond number, [dimensionless]
We	Webber number, [dimensionless]
DO	Dissolved oxygen concentration, [mg/L]

Subscripts

c	Critical
f	Water film over tray
j	Water jet from tray
o	Outer
S	Saturation
$0,1,2$	Initial, intermediate, final

spacing (SP) between trays. Each tray is made from a flat sheet with a number (n) of holes each with a diameter (d). When water falls over trays, a thin film of water with height (h) forms over the tray before the water exits from the holes. Trays are constructed with sides having height (h_s) exceeding the thin film height to prevent overflow from the sides. Fig. 1 illustrates the main parameters of tray aerators. Subsequent sections of the current work discuss the approach of the authors to develop a model for designing and estimating the *DO* effluent from tray aerators.

Tray aerators were studied for the stripping purpose, that is the removal of unwanted gases from water. They were investigated for the purpose of iron and manganese removal in water treatment plants [10], carbon dioxide stripping for clean water [11,12] and

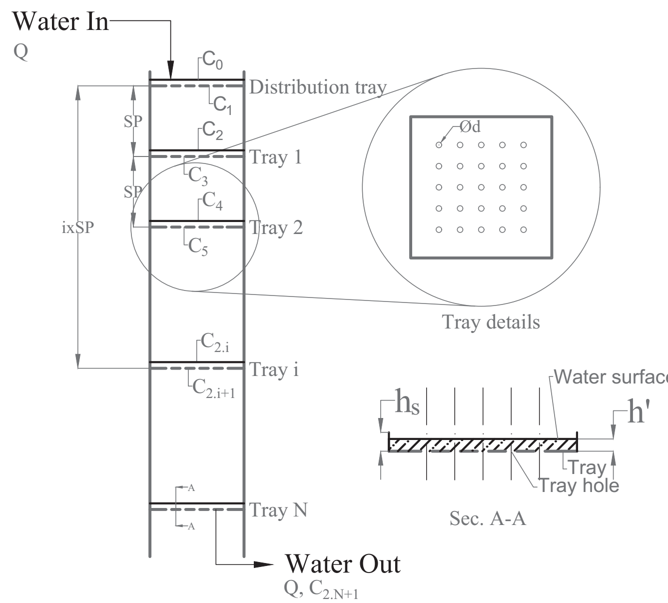

Fig. 1. Tray aerator setup.

stripping of sulfides from ground water [13]. Few studies, if any, addressed the use of tray aerators for aeration purpose.

The current work investigates the effect of different regimes of free falling flow on the performance of tray aerator. In addition, a design model for the aeration through tray aerator is developed and discussed in the current work. This model includes the potential design parameters of tray aerator. The study also investigates the effect of varying each design parameter on the aeration performance of tray aerator.

2. Materials and methods

2.1. Background on aeration process

Aeration of water is a mass transfer process, with the concentration gradient acting as the driving force. Any constituent tends to transfer from the zone of high concentration to the zone of low concentration until both zones reach an equilibrium state with similar concentrations as illustrated in Fig. 2. The rate of oxygen transfer to water across an air-water interface can be described with Eq. (1) which is based on Fick's first law of diffusion [14,15]

$$V\frac{\partial C}{\partial t} = K_L A(C_S - C) \quad (1)$$

where (V) is the volume of water over which (C) and (A) are measured; (C) is the concentration of oxygen in water; (t) is the time; (K_L) is the overall liquid mass transfer coefficient; (A) is the interface area; and (C_S) is the saturation concentration of the gas in water and is equal to the partial pressure of oxygen in water divided by Henry's law constant. The value of C_S depends on the water temperature, barometric pressure and water salinity. It is obtained from published data and tables [16].

For the tray aerator system, Eq. (1) can be manipulated and integrated across the limits of time from zero to t, and the concentration from the initial concentration to the concentration at time t, to reach the form illustrated in Eq. (2).

$$\ln\left(\frac{C_S - C_t}{C_S - C_0}\right) = -K_L a t \quad (2)$$

where (C_t) is the concentration at time t; (C_0) is the initial concentration; (a) is the specific area which is equal to the ratio