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Wastewater remediation by optimum dissolve oxygen enhanced by macrophytes in constructed wetlands

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ABSTRACT

As new ways are being sought to treat wastewater in natural and constructed wetlands (CWs), the role of oxygen released by the macrophytes for degrading organic waste has inordinate significance. The current investigation assessed the optimum dissolve oxygen (DO) added by *Typha latifolia* and *Phragmites australis* when exposed to the optimum temperature and light intensity. A wireless network system (WSN) monitored the environmental conditions which was designed and deployed at the experimentation site. The plants were exposed to 16 different combinations of temperature and light intensity. The optimum DO in the rhizosphere of *T. latifolia* was recorded when plants were exposed to 30 °C and 35 °C implying that the optimum temperature range was 30–35 °C with 15 000 lx light intensity. The optimum DO in the rhizosphere of *P. australis* was recorded when plants were exposed to the 35 °C temperature and 10 000 lx to 15 000 lx light intensity. A strong correlation was found between DO, total chlorophyll and fresh plant biomass at the optimum temperature and light intensity combinations in both plants. The maximum DO in the substratum of CWs proved to play a significant role in reducing hydraulic retention time (HRT) in vegetated CWs.

1. Introduction

With the advent of industrialization and use of chemicals for domestic purposes, agriculture and pharmaceutical products, the conventional treatment systems are unable to abate the environmental pollution (Hayder et al., 2015). CWs have the potential to achieve the required treatment goals at low cost and energy utilization as compared to the conventional treatment systems (Mthembu et al., 2013). However, old fashioned CWs would not be effective for the treatment of large volume of wastewater containing emergent pollutants. In CWs, macrophytes play a vital role in wastewater treatment through nutrients, salts and heavy metals uptake and release of oxygen in rhizosphere (Vymazal, 2011; Wenlin et al., 2014). The oxygen release by plants in the rhizosphere augments degradation of organic matter in wastewater. However, this oxygen might become a rate limiting factor in constructed wetlands (Brix, 1994; Uteau et al., 2015). Some scientists demonstrated that a part of the oxygen produced as a byproduct during photosynthesis is transported to the aerenchyma cells which are a structural adaptation of the aquatic macrophytes (Connel et al., 1999; Headley and Tanner, 2008; Zhang et al., 2014). The oxygen released from the roots of *Potamogeton perfoliatus* (submerged macrophytes) was directly proportional to the rate of photosynthesis in plant shoot. Thus when the amount of O_2 in the aerenchyma cells and root region surpasses the plant demand, diffusion may occur into plant rhizosphere (Armstrong, 1979; Brix, 1997). However, it is also believed that a significant amount of oxygen is also transported from the atmosphere to the rhizosphere through macrophytes e.g. in *Nuphar lutea* in which oxygen entered the youngest emerged leaves due to gas pressure gradient and entered into the petioles and large blades of older leaves (Armstrong and Armstrong, 1988; Konnerup et al., 2011). Moreover, the direct diffusion of oxygen was observed in emergent plants with cylindrical culms and linear leaves e.g. *P. australis* (Pedersen et al., 2004; Afreen et al., 2007).

T. latifolia and *P. australis* are the emergent macrophytes having an effective aeration system and large intercellular spaces meant for oxygen within plant to accomplish the respiratory demand of submerged tissues and rhizosphere. Additionally, the ability of reeds to transport oxygen to the rhizosphere is proved to be a crucial mechanism in the removal of BOD and nitrogen (Lavrova and Koumanova, 2013). This oxygen release from the roots of macrophytes is affected by physical factors. It can be maximized to enhance the pollutant removal in CW using different macrophytes under same climatic conditions, types of wastewater, substrate type and same species of macrophytes under different climatic conditions. Large differences were found in efficiency of same species to remove one or more types of pollutants and the selection of

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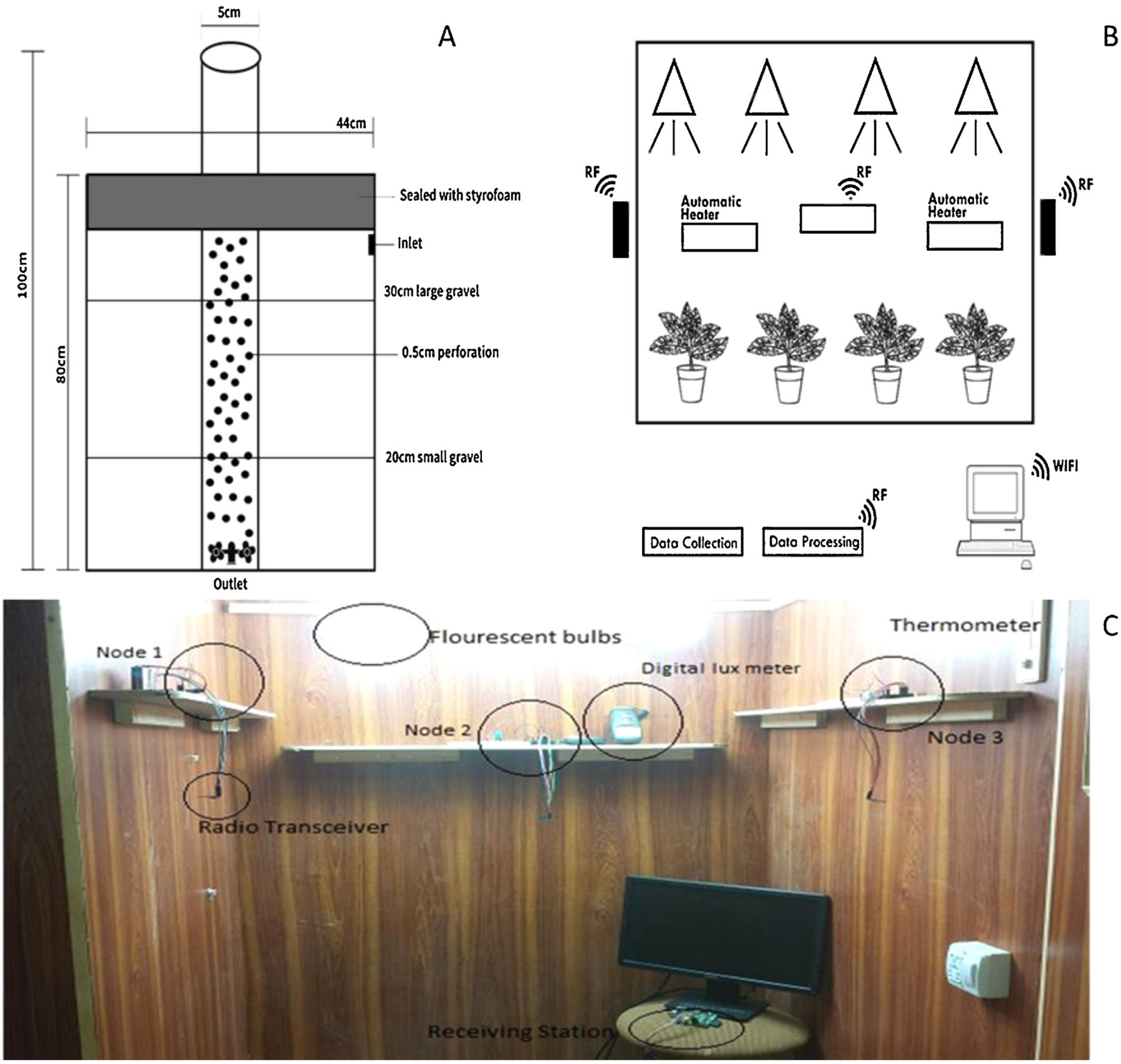

Fig. 1. (A) Design of a vertical flow constructed wetland with two types of gravel used as substratum and a perforated PVC pipe inserted in the center for measuring dissolved oxygen. (B) The growth chamber with deployed wireless sensor network having three sensor nodes, a data collecting and processing point, two communication technologies and a display system. (C) Photograph of the growth chamber with deployed wireless sensor network. Three nodes are composed of temperature, humidity and light intensity sensors.

Table 1
Composition of synthetic wastewater.

Synthetic influent	Concentration
Analytical grade glucose	As per requirement
$NaHCO_3$	1 g/L
Trace element solution	1 ml/L
$MgCl_2$	1 g/L
KH_2PO_4	1 g/L
$(NH_4)_2SO_4$	0.24 g/L

Table 2
Components of nutrient solution.

Components (g/L)	Components (g/L)	Components (g/L)
Na_2-EDTA 5	$FeCl_2{\cdot}4H_2O$ 3.58	$CoCl_2{\cdot}6H_2O$ 0.5
NaOH 11	$MnCl_2{\cdot}2H_2O$ 2.5	$(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$ 0.5
$CaCl_2{\cdot}2H_2O$ 7.34	$ZnCl_2$ 1.06	$CuCl_2{\cdot}2H_2O$ 0.14

macrophyte species is sometimes important for the removal of certain pollutant under specific environmental conditions (Wiebner et al., 2002; Brisson and Chazarenc, 2008). Similarly the growth stages of different macrophytes also affect the release of oxygen. In *P. australis* the oxygen released during budding, elongation, maturation, and dormancy phases was three times higher than the oxygen released during the growth stages of other plants (Zhang et al., 2014).

Scientists are working on automated systems also called Wireless Sensor Networks (WSN) to monitor and control the environmental conditions within the greenhouses and fields to get the maximum possible process control. Small size and data sensing accuracy, high sampling frequency, energy efficient battery powered compressed ready-to-deploy units make wireless sensor enabled technologies ideal for environmental sensing applications. Multiple sensing nodes equipped with sensing elements like temperature, light humidity, wind speed, gases concentration, soil/atmospheric moisture level etc. (Akshay et al., 2012). The present study aimed to investigate the optimum DO levels added by the *P. australis* and *T. latifolia* to the substratum of the CW under controlled temperature and light intensity combinations. Further-