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A Review on Design Basis for Constructed Wetlands for Wastewater Treatment

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Abstract: Since last few years Constructed Wetlands (CWs) are being used to treat secondary or tertiary municipal or domestic wastewater effluents have been recognized as an effective means of "green technology" for wastewater treatment. Constructed wetlands (CWs) provide a natural way for simple, inexpensive, and robust wastewater treatment. The idea of natural management systems is the restoration of disturbed ecosystems and their sustainability for remuneration to nature. The Constructed wetlands (CWs) are designed to copy natural wetland systems, utilizing wetland plants, soil and associated microorganisms using various biological, physicochemical processes to remove unwanted constituents from wastewater effluents. This review paper studies various types of constructed wetlands, i.e., surface or subsurface, vertical or horizontal flow and their type of operation, i.e., continuous, batch or intermittent flow, loading rate, selection of plants and wastewater characteristics that affect the treatment efficiency. The design models with their suitability for various parameters and operational conditions such as Darcy's equation, Kadlec and Knight Model (K-C* model), Arrhenius equation, and population equivalent calculation have been discussed. Lastly, future research requirements have been considered.
Keywords: Wetland, designing parameters, hydraulic loading rate, hydraulic retention time, population equvivalent

I. INTRODUCTION

Constructed wetlands(CWs) comprise of vegetation, substrates, soils, microorganisms and water, will utilize physical, chemical, and biological mechanisms to remove various pollutants or enhance the water quality [1,2,3,4].
According to the method of application of wastewater to the substrate, the constructed wetlands are classified into: free water surface (FWS) CWs and sub-surface flow (SSF) CWs [4]. In SSF systems, wastewater flows horizontally or vertically through the substrate, respectively known as, vertical flow (VF) and horizontal flow (HF). FWS systems are similar to natural wetlands, with shallow flow of wastewater over saturated substrate. The design criteria for any CWs include site selection, selection of native plants, substrate selection, hydraulic retention time (HRT), wastewater type, hydraulic loading rate (HLR), water depth, and operation mode. Sizing of a constructed wetland is the most important factor affecting wetland performance [1, 5, 6]. Different models have been used to design the wetlands based on the influent BOD_5 concentration or organic loading rate [2,7,**8]**. In most of the models, variations like order of the reaction, flow kinetics such as plug-flow kinetic or intermittent-flow kinetic relationships are available [9]. The following parameters are used in the design attempts to mimic CWs to the natural wetlands in overall structure, simultaneously to develop those wetland processes that are thought to contribute the most to the enhancement of water quality.

II. DESIGN PARAMETERS

Some literature is available that reviews the design, operation, and performance of different types of CWs. However, in this review paper, attempt has been made to present a comprehensive coverage of different works on various design and operation parameters enhancing the performance of CWs in terms of BOD reduction. The main parameters being discussed here are organic loading rate, hydraulic loading rate, and hydraulic retention time.

A. Organic Loading or BOD_5 Loading Rates or population equivalent based BOD_5 loading

Organic loading rate is represented as the mass of organic matter (BOD) applied per day over a unit surface area, for example kg/ha.day. Unevenly distributed heavy organic loading, cause death of the plants and odour problems [2]. Organic loading in a FWS wetland can be controlled by step-feed distribution as well as recirculation of wetland discharges [10]. Following table 1 showsa summary of different studies based on BOD loading and outlet BOD in various CWs.The results from these studies show that less than $10 g/m^2$.dayBOD loading will reduce BOD up to 30mg/l with 80-90 % removal of BOD.

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Table 1. BOD loading and outlet BOD

Sr No.	Authors' detail	Inlet BOD	Outlet BOD
1	EPA [2]	4.5g/m^2	< 30 mg/l
		6 g/m^2	< 20 mg/l
2	Hammer [11]	10 g/m^2	< 30 mg/l
3	Schierup et al.[16]	5 g/m^2	80-90% removal
4	klomjek and Nitisoravut [17]	11.2-13.8 g/m^2	50% removal
5	Sohair et al. [18]	2.52 kg/m^3/d	92.8%

Researchers have also used a simple parameter to determine the surface area of CWs based on influent organic loading per unit surface area per population equivalent. Most effective area for FWS,based on this approach, has been reported as 2-5M^2/PE by Crites [7] and Brix[15]; whereas, Wood & McAtamney[16] used generalized 'design rule' of allowing up to 5 m^2 bed for a 40 g/ d BOD load (one person equivalent) providing modest spare capacity for treatment of landfill leachate using laterite as substrate for horizontal subsurface flow. Whereas Kadlec & Wallace [17] and Vyzmal [18] used 2-3 M^2/PE loading for vertical flow CWS. The following equation has been used to calculate population equivalent or per capita loading (PE):

$$PE = \frac{\text{Total BOD load}}{\text{Percapita BOD load}} \quad (1)$$

B. Hydraulic Loading Rate

The hydraulic loading rate is represented as volume of influent per day applied over a unit surface area. It does not indicate uniform distribution of water over the wetland surface [6].It is calculated as follows:

$$HLR = Q/A \quad (2)$$

where: A = wetland wetted area (m^2), and Q = water flow rate (m^3/day)[2].

Kadlec and Knight[8]recommend the k–C* model as an alternative to the Metcalf & Eddy [19] models. The k–C* Model is based on an areal loading equation and is as follows:

$$\text{Surface area} = \left(\frac{Q}{k}\right)\ln\left(\frac{[Co - C^*]}{[Ci - C^*]}\right) \quad (3)$$

Where: *Q*=Annual flow (m^3/y); *k*=Rate constant (m/y); *C*i=Inflow concentration (mg/l); *C*o=Outflow concentration (mg/ l); *C**= Background concentration (mg/l).

According toKadlec and Knight[8] background concentration can be calculated by the equation:

$$C^* = 3.5 + 0.053Ci \quad (4)$$

The typical value for C^*being commonly used is 10mg/l [2]. This equation is also based on first-order kinetics, and the values for the constant *k* are temperature dependent[20]. The temperature effect on rate constant *k* is calculated by Arrhenius equation:

$$K = K_{20} \times \Theta^{(T-20)} \quad (5)$$

Where: k_{20}=Rate constant at 20°C with a suggested value of 0.23 d^{-1}.;Θ = thermal coefficient (dimensionless), with a suggested values of 1.03; *T*= Water temperature (°C).

Above equation (5) is used for determining HLR

$$K = HLR(\ln(C_{in} - C_{out})) \quad (6)$$

C. Hydraulic Retention Time:

The Hydraulic retention time (HRT, t) is a determine of the average length of time that a soluble constitute remains in a constructed bioreactor [15,**13]**. Large dead spaces may be created in the wetlands due to differences in topography, plant growth pattern, solids sedimentation rate, and short circuiting makes estimation of HRT difficult [2]. Only a fraction of the surface area, in wetlands, may be available for wastewater flow [7]. The minimum required surface area to provide the required hydraulic residence time is estimated by the following relationship [19]:

$$\text{Surface area needed} = t/[d \times \left(\frac{p}{q}\right)] \quad (7)$$

where: *t*=HRT (days); *d*= average water depth (m); *p*= porosity of the wetland, defined as the proportion volume of plants to total water volume with values varying from 0.86 to 0.98 depending on the type of plant used [2]; *q*= flow rate (m^3/d).

Based on the experimental data and on the first-order model reaction kinetics the calculation of the HRT has been given byMajer Newman, Clausen, and Neafsey [22]as:

$$t = 2.7(\ln C_{inlet} - \ln C_{outlet} + \ln A)/1.1^{(T-20)} \quad (8)$$

Where: C_{inlet}= Influent BOD_5 concentration (mg/l); C_{outlet}= Desired outlet BOD_5 concentration (mg/l); A=the ratio of soluble BOD_5 to total BOD_5, and is not to exceed 0.90; *T*=Yearly mean wetland water temperature.

The nominal hydraulic retention time (HRT) is defined as the ratio of the utilizable wetland water volume (V_w) to the average flow rate (Q_{ave}) which can be calculate by following equation:

$$t = \frac{(Vw)}{Qactual} \quad (9)$$

The average wetland flow which is represented as Q_{actual} is used to calculate the hydraulic retention time. The relationship among flow through a porous media and the hydraulic gradient is typically described by the general form Darcy's equation:

$$Q = (K)(A_c)(S) \quad (10)$$

Where: Q= flow rate, m^3 /d; K = hydraulic conductivity, m^3/m^2/d; Ac = cross-sectional area normal to wastewater flow

Based on a long-term experiment Cui et al.[23];and Chavan & Dennett[24] have given following HRT equation:

$$\text{HRT} = 0.84 \times \frac{V}{Q_{actual}} \times (1 - e^{(-.059 \times \frac{x}{y})} \quad (11)$$

Where V= wetland volume (m^3), L= wetland length (m), and W= wetland width (m). Hydraulic loading rate (m/day) is calculated as area to flow ratio and Velocity (m/day) through the wetland is calculated as L/HRT [25]. In above equation peak discharge can be used by multiplying the Q_{actual} by Harmon's peaking factor (PF). PF can be calculated by following equation:

$$\text{PF} = 1 + \left(\frac{14}{4+\sqrt{P}}\right) \quad (12)$$

Where: P=population in thousand

The above design parameters helps in better operation of CWs for wastewater treatment. However the review on plants by Jethwa and Bajpai [27] indicatesthat wetland macrophytes are still critical issue for the sustainable containment removal from wastewater in CWs. Selection of appropriate plants and density of plants also major role in pollutant removal.

III. DISCUSSION

The current studyshowed that basic parameters in the design and operation of CWs have greatly increased pollutantremoval efficiencies, has also been improved.Table 2 shows the summary of parameters recommended by various researchers for design of CWs for BOD loading, HLR, Length: Width ratio, DT and the slope as the design criteria, but average temperature throughout the year was not considered as a key parameter in that summary. However, Metcalf & Eddy [20]has mentioned the rate of reaction will depend on the temperature of the region.

Table 2 Summary of design criteria

Design parameter	Crites [7]	Bendoricchio [26]	Wu et al[1]	EPA[2]
BOD loading(g/m^2)	11.2	8-11.2	--	8-11.2
HLR(m/d)	0.0254-0.127	0.01-0.05	2.7x 10^{-4}	0.01-0.05
Aspect ratio	2:1-4:1	-	3:1-5:1	3:1-5:1
Detention time(d)	2-5	5-14	5-30	5-14
Aquatic plant used	Water hyacinths	--	--	--
Slope	-	0-0.5%	<0.5	0-0.5%
BOD removal achieved	< 30 mg/l	--	--	< 30 mg/l

The above summary table showed that design parameters of Crites [7]and EPA [2] helps in achieving BOD removal up to 30 mg/l. Further more, design criteria such as selection of maycrophytes and it's density and effects of different temperature should be focus for future research work.

IV. CONCLUSION

From the various equations for designing it is enlisted that the factors for CW design such as, organic loading rate, hydraulic retention time, Length to width ratio, water depth, flow velocity, and feeding mode are key to get the desire range of contaminants from the wastewater. Temperature also play major role for increase rate of reaction, for selecting any design basis designer should considered average temperature throughout the year. For effective and sustainable application of CWs, future studies should focus on plants density and harvestibility in a different types soil.

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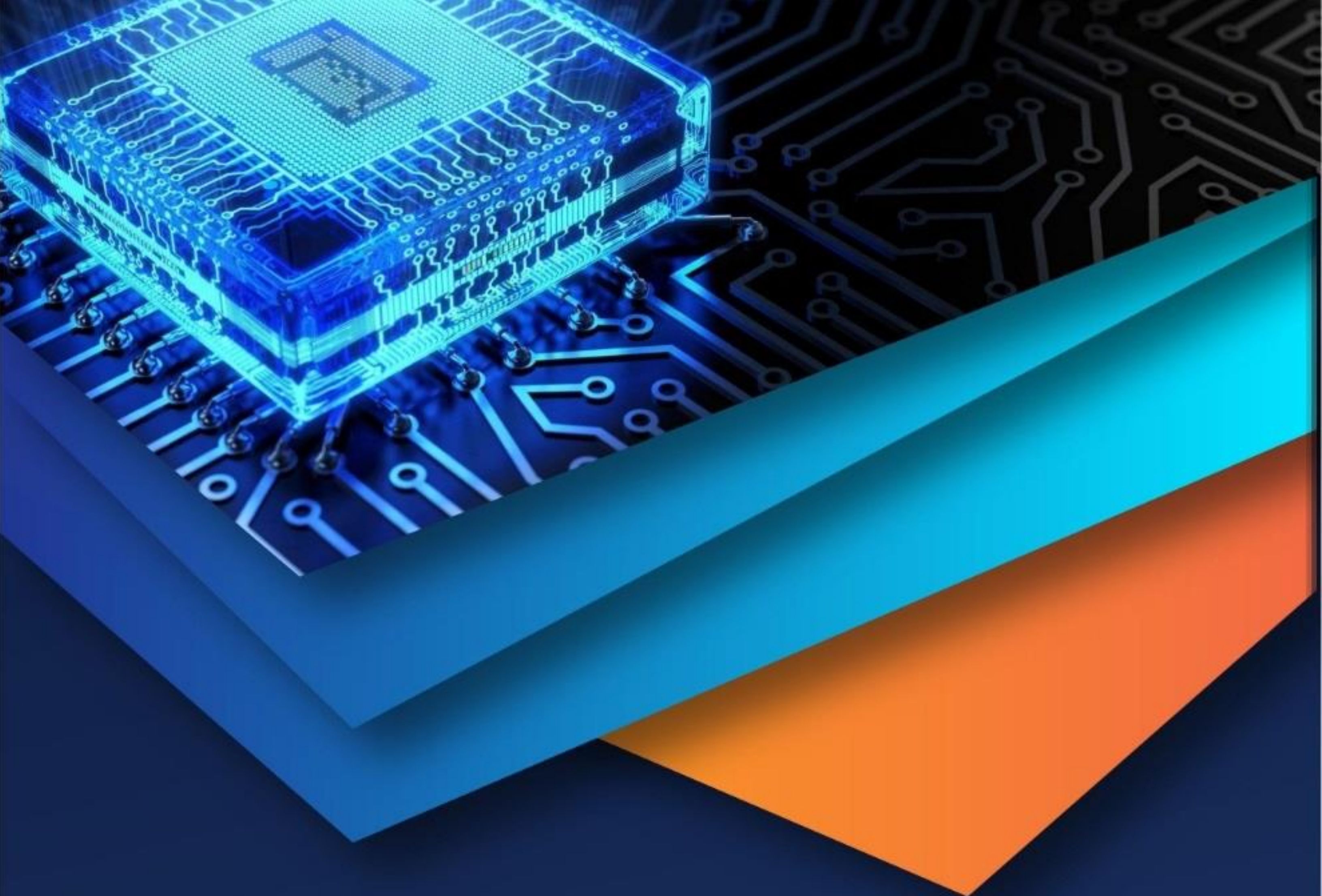

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