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REVIEW

A Review On Sub-Surface Flow Constructed Wetlands In Tropical And Sub-Tropical Countries

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Abstract:

Water pollution is mostly caused by direct disposal of waste to the ground or river without prior treatment. Several methods had been proposed to overcome the pollution, e.g. by treating the waste prior disposal or by applying artificial wetland systems (constructed wetlands) to treat domestic wastewater. Artificial wetland systems (constructed wetlands) resembles water treatment processes in natural wetlands, that utilizes hydrophytes to symbiose with the microorganisms in the media around the rhizosphere of the plants. A good example of the plant is *Cyperus alternifolius,* a plant that grows rapidly in wet environments. This plant has a triangular stem, with adult stem height ranged between 0.5-1.5 m. Organic materials contained in the wastewater will be cleaved by the microorganisms into simpler compounds and will be consumed by the plants as a nutrient, while the root system of aquatic plants will produce oxygen that can be used as a source of energy or catalyst for a series of metabolic processes for heterotropic aerobic microorganism. In general, horizontal flow SSF-Constructed Wetlands (hSSF-CW) is being used continuously and applied in many tropical countries. SSF-CW is a good choice for wastewater treatment due to its low maintenance costs and simple operational.

Keywords: : Cyperus alternifolius, rhizosphere, water pollution, wetlands

Introduction

The largest contributors of water pollution (60-70%) are domestic wastes (sanitation, garbage, surfactant, etc.) due to their direct disposal to the ground or river without prior treatment. Several methods had been proposed to overcome the pollution, e.g. by treating the waste prior disposal or by applying artificial wetland systems (constructed wetlands) to treat domestic wastewater (Ismuyanto, 2010). Constructed wetlands system (CW) is a wastewater treatment process that is adapted from wastewater treatment process by natural wetlands, wherein aquatic plants (hydrophytes) has an important role in the self-purification process (Hammer, 1986). Two types of CW according to its location are (1) surface flow and (2) subsurface flow, whilst based on the type of plants used, the constructed wetlands is divided into (1) floating aquatic plant system, (2) submerged aquatic plant system and (3) amphibious aquatic plant system (Metcalf & Eddy, 2003).

Sub-surface Flow Constructed Wetlands (SSF-CW) is utilizing a symbiosis between aquatic plants and microorganism in the media around the root system (rhizosphere). Complex organic compounds contained in wastewater will be consumed by the plants as a nutrient, while the root system of aquatic plants will produce oxygen that can be used as a source of energy or catalyst for a series of metabolic processes for heterotropic aerobic microorganism (Mitchell, Wiese and Young, 1998).

SSF-CW is a good choice for wastewater treatment due to its low maintenance costs and simple operational. Plants that are usually used include *Cyperus alternifolus, Canna indica, Phragmites australis, Typha spp, Scirpus spp,* etc. These plants reduce the concentration of BOD, COD, ammonia, nitrites, phosphorus and bacterial contaminants (Greg, Young and Brown, 1998).

In the outline, several advantages of SSF-CW are (Kadlec and Knight, 1996): (1) Simple to be constructed; (2) Could be placed anywhere (indoor or outdoor); (3) Discretion in operating system (e.g. gravity system or pump system); (4) Low cost, e.g. a gravity system utilizes solar energy; (5) No odor arises since it is not in contact with the air; (6) Performance can be relied; (7) No breeding ground for insect and (8) Displayed as a garden that has an aesthetic value.

SSF-CW could be used to treat domestic waste, agricultural and some industrial waste, including heavy metals. This method has a high efficiency (80%), whilst its cost of planning, operation, and maintenance are low. In addition, the system has a high tolerance to fluctuations in wastewater discharge. It can be applied to treat the wastewater with high differences types of pollutants and concentration and allowed for the implementation of reuse and recycle. As the processing of domestic wastewater, constructed wetlands must be designed for fulfilling the aesthetic functions, so it can be displayed as aquatic plants at home (Haberl and Langergraber, 2002).

Four factors or components that affect SSF-CW system performance (Crites and Tchobanoglous, 2003) are: media, plants, microorganisms, and temperature.

(1) Media

The level of permeability and hydraulic conductivity of the media is very influential on the retention time of wastewater, in which the retention time is enough to give a chance to contact between microorganisms in wastewater, and oxygen released by plant roots. Characteristics of the media in the SSF-CW can be seen in Table 1:

Table 1. Characteristic of Media in SSF-CW

Type of Media	Grain Diameter (mm)	Porosities (η)	Hydraulic Conductivity (ft./d)
Medium Sand	1	0.30	1,640
Coarse Sand	2	0.32	3,280
Gravelly Sand	8	0.35	16,400
Medium Gravel	32	0.40	32,800
Coarse Gravel	128	0.45	328,000

Source: Crites & Tchobanoglous (2003)

The main function of the media in the SSF-CW are places for plants to grow, media proliferating microorganisms, helping the process of sedimentation, as well as helping the absorption odor of the gases of biodegradation. While other role in the transformation process is a chemical, materials storage nutrient required by plants (Khiatuddin, 2003). Performance of SSF-CW based media used can be seen in Table 2.

Table 2. Performance of SSF-CW Media

Type of Media	Percentage Decrease of Pollutant		
	BOD	SS	Coliform
Gravel	55-96	51-98	99
Soil	62-85	49-85	-
Sand	96	94	100
Clay	92	91	-

Source: Khiatuddin (2003)

(2) Species of plants

Plants used for SSF-CW are submerged plants or amphibious plants (Table 3). The most important factor when selecting a plant is its ability to absorb nitrogen (N) and phosphorous (P) from the environment. N & P absorption ability for some types of plants can be seen in the Table 3.

Table 3. N & P Absorption Ability of Hydrophytes

Type of Hydrophytes	Absorption Ability (kg/ha/yr.)	
	N	P
Cyperus alternifolus	1,100	50
Typha latifolia	1,000	180
Eichornia crassipes	2,400	350

Pistia stratoites	900	40
Potamogeton pectinatus	500	40
Certophylum demersum	100	10

Source: Brix (1994)

Cyperus alternifolus is an ornamental plant species that can be used for domestic wastewater treatment. The taxonomy of *Cyperus alternifolus* is:

Division: Tracheophyta
Class: Angios-permae
Sub-Class: Monocotyledoneae
Family: Cyperaceae
Genus: Cyperus
Species: *Cyperus alternifolius.*

Figure 1. *Cyperus alternifolius* (copied from commons.wikimedia.org)

Cyperus alternifolius originally came from Madagascar. This plant grows rapidly in wet biosphere (aqueous), with height variation ranged between 0.5-1.5 m. The leaves are narrow and long, ranged between 12-15 cm. The small flowers grow at the center of the green leaves. Cyperus alternifolius has a good ability to absorb nitrogen (N) and phosphorus (P) than other crops used in constructed wetlands system is still good enough (Lukito, 2004).

(3) Microorganisms

Preferably are heterotrophic aerobic microorganisms due to their faster processing ability than the an-aerobic types. The oxygen content in the media will be supplied by plant roots, which is a byproduct of the process of photosynthesis of plants with the help of sunlight.

(4) Temperature

The temperature of wastewater affects the activity of microorganisms and plants, furthermore it will affect the performance of processing.

Process in constructed wet-lands (cw)

There are several processes that occur in the CW in eliminating or reducing the content of contaminants. The processes are physical, chemical and biological. Pollutant reduction mechanism is provided in Table 4.

Table 4. Decrease Mechanism of Pollutants

Pollutant	Process
Organic Compound	Biology process, sedimentation, absorbed by microorganism
Organic Material	Adsorption, volatilizes, photolysis, biotic/abiotic degrades
Suspended solid	Sedimentation

Source: Mitchell, Wiese and Young (1998)

SSF-CW system is the most suitable method for primary processing of wastewater. This method employs no direct contact with the pool water and the atmosphere. SSF-CW systems are very useful in processing the flow of domestic waste or local used water, but it is also applicable for the treatment of leachate and other waste that requires the removal of organic material at high concentrations such as nitrates, pathogens and other pollutants.

SSF-CW system also depends on the diversity of species, because the availability of oxygen supplied to the waste water by the roots of the plant and reused for biofilm growth directly at the roots and rhizomes. Unfortunately this system is not able to oxidize ammonia (nitrification) due to lack of available oxygen which is main reason of its disadvantage. For ammonia-contained waste, the ammonia removal process is more effective by using anaerobic conditions (Dallas, Scheffe and Ho, 2005).

In general, horizontal flow SSF-Constructed Wetlands (hSSF-CW) is being used continuously and applied in many tropical countries. SSF-Constructed Wetlands is a good choice for wastewater treatment due to its low maintenance costs and simple operational.

The vertical flow SSF-CW (vSSF-CW) is more often used in sub-tropical countries. A common problem is a blockage in hSSF-CW, especially around the entry zone. Generally this happens because the design is less hydraulics, less flow distribution at the inlet and less precise choice of porous media, the overall system, or a combination of various factors. The problem can be overcomed by placing a gravel with a diameter of 50 mm around the inlet zone (Sarafraz et al, 2009).

The performance of SSF-CW could be assessed from its ability to reduce the levels of pollutants or pollutant parameters. Research showed that % reduction in BOD of the pollutants is up to 99.7% (Raude et al, 2009). Limitations SSF-CW in improving the quality of wastewater are (Greg, Young and Brown, 1998): (1) The speed of the process depends on environmental factors (temperature, oxygen, pH, etc); (2) Hydrological limitation when the debit exceeds the capacity; (3) Limitations of the environment for organic material, nutrients or toxins, and lack of oxygen; (4) Limitations of land, hence the dimensions of SSF-CW are not in accordance with the desired residence time.

Technical design of constructed wetlands

In CW, wastewater treatment process occurs through filtration, sedimentation, the absorption by the microorganisms and adsorption of pollutants by soil (Crites, 2003).

Table 5. Design Criteria and Effluent Quality of SSF-Constructed Wetlands

Parameter	Unit	Value
BOD	$gr/m^2.day$	<7,5
TSS	$gr/m^2.day$	40,3
Insect Control	-	n/a
Detention Time	Day	2-7
Water Depth	m	0,1-1
Harvesting Frequency	Year	3-5
Hydraulic Loading Rate	mm/day	2-30
Media Depth	m	0,45-0,75
Effluent Quality		
BOD_5	mg/L	<20
TSS	mg/L	<20

Source: Crites and Tchobanoglous (2003)

The formula in the design of SSF-CW are (Metcalf and Eddy, 2003):

1. Detention Time

$$\frac{C_e}{C_o} = e^{-k_1 - td}$$

$$K_t = K_{20}\,(1{,}1)^{r-20}$$

$$td = \frac{-\ln\left(\frac{C_e}{C_o}\right)}{K_s.\,S}$$

$$A_s = d.\,W = \frac{Q}{K_s.\,S}$$

$$L = \frac{td.\,Q}{W.\,d.\,\alpha}$$

$$A_s = L.\,W$$

Where:

Q = Flow rate (m^3/day)
As = Surface area (m^2)
T = Temperature (^{0}C)
Ks = Hydraulic Conductivity (m/day)
α = Media Porosity
K20= Standard Coefficient in 20^0C
C0 = BOD influent (mg/L)
Ce = BOD effluent (mg/L)
S = Media Slope

td = Detention Time (day)
d = Depth (m)
W = Width (m)
L = Length (m)

2. Loading Rate

$$L_w = \frac{Q}{L.W}$$

$$BOD_{lr} = \frac{Q.C}{A}$$

Where:
Lw = Hydraulic loading rate
BODlr = BOD loading rate
C = BOD Concentration (mg/L)

Construction wetlands in tropical and sub-tropical countries

CW in the tropical areas have been applied in Nakura City (Kenya) to treat domestic waste (gray water) with an average temperature of 30^0C. CW was applied at laboratory scale with the size of $2m^2$ with a depth of 0.86 m which had previously been carried for pretreatment of wastewater. The residence time of wastewater in the reactor in 2 days showed the following results (Table 6) (Raude et al, 2009):

Table 6. Performance of SSF-CW in Tropical Zone

Parameter	Unit	Influent	Effluent	Reduces (%)
EC	µS/cm	1929.00	1644.00	14.0
Salinity	g/L	1.00	0.80	20.0
DO	mg/L	3.01	0.08	97.4
TDS	mg/L	1257.00	1084	14.0
BOD_5	mg/L	104.00	0.33	99.7
TSS	mg/L	255.00	9.00	97.0
TP	mg/L	2.43	0.29	88.0
FC	Log 10 FC/100 mL	4.97	4.09	18.0
NH_4	mg/L	3.17	0.09	97.0

Source: Raude et al (1998)

SSF-CW treatment in 2 days reduced of 97% of TSS and 99.7% of BOD5. Using 2 stages of SSF-CW with support of plants Colix zizonioides decreased 99.4% of BOD and decreased 99.9% of coliforms (Dallas, 2006).

Other CW was performed on the sub-tropical average temperatures 4^0C, in McGrath Hill City (Australia). Domestic sewage flowed into the reactor (ratio of length and width is 2.6:1, with a slope of 1%). The reactor was designed with hydraulic loading of 0.02 m^3, average discharge of 2.8 m^3/day and detention time for 2 days. The results of domestic wastewater treatment using this system is showed in Table 7 (Campbell and Ogden, 1999):

Table 7. Performance of SSF-Constructed Wetlands in Sub-Tropical Zone

Parameter	Unit	Influent	Effluent	Reduces (%)
pH	-	7.12	6.97	2.1
TDS	mg/L	223.00	66.87	70.8
BOD_5	mg/L	190.00	39.14	79.4
COD	mg/L	258.00	78.17	69.7
TSS	mg/L	257.00	21.07	91.8
TP	mg/L	8.00	3.00	62.5
NH_4	mg/L	43.00	32.04	25.5

Source: Campbell and Ogden (1999)

Conclusion

Several methods had been proposed to overcome the pollution, e.g. by treating the waste prior disposal or by applying artificial wetland systems (constructed wetlands) to treat domestic wastewater. SSF-CW resembles water treatment processes in natural wetlands, that utilizes hydrophytes to symbiose with the microorganisms in the media around the rhizosphere of the plants. This system has been proven in improving the quality of wastewater, therefore it could potentially be used as an attempt to solve wastewater problems, especially for those who need cost efficient.

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