International Journal of Environmental Science and Technology (2019) 16:6453–6472
https://doi.org/10.1007/s13762-019-02472-7

REVIEW

Wastewater treatment of food industries through constructed wetland: a review

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Received: 10 April 2019 / Revised: 25 June 2019 / Accepted: 9 July 2019 / Published online: 15 July 2019

Abstract
Constructed wetland (CW) is reliable technology for a range of wastewater treatment generated through various sources. Contrary to traditional wastewater treatment technologies, CW is an environment friendly and profitable approach with less personal supervision requirements. Moreover, CW has been successfully implemented for diverse agriculture and industrial sectors for sewage or municipal wastewater treatment. In this review, recent developments in constructed wetlands related to various food industries such as seafood-processing industry, olive mill industry, dairy, alcohol fermentation industry and abattoir industry at both laboratory- and pilot-scale levels are presented. It has been found that high pollutant loading rates and toxic substances can be effectively treated with CW; thus, they have great potential to be easily operative in developing countries and rural areas. Finally, some challenges that may affect the performance of CWs with some suggestions to improve their performance are also discussed.

Keywords Abattoir industry · Constructed wetland · Influent · Surface loading rate · Wastewater treatment · Wineries

Abbreviations

CW	Constructed wetland
SSF-CWs	Subsurface flow
HF	Horizontal flow
VF	Vertical flow
FWS-CWs	Free water surface constructed wetland
HCW	Hybrid wetland
NH_4^+–N	Ammonium nitrogen
TP	Total phosphorous
COD	Chemical oxygen demand
BOD	Biological oxygen demand
TSS	Total suspended solids
NO_3^-N	Nitrate nitrogen

Editorial responsibility: M. Abbaspour.

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Introduction

Water being the major necessity of life is facing global crisis of scarcity, ground and underground water pollution along with rapid depletion of natural water reserves. The situation is becoming more alarming due to continuous increase in population worldwide, environment unfriendly activities and the increased production of industrial discharge. Besides, various other industries discharging effluent from food-related industries (abattoir dairy, alcohol fermentation, oil mills, aquaculture and seafood-processing industry, etc.) contribute to dumping off excess nutrients and organic content in freshwater streams resulting in eutrophication of ground and surface water (Kominami and Lovell 2012). Further, such high-strength discharged effluents are pollution sources of diffuse and non-point sources, contamination of surface and groundwater, siltation and toxic to land and marine organisms, thus affecting natural ecosystem, flora and fauna, fisheries and public health (Carty et al. 2008). Therefore, strict legislations are proposed from environmental protection agencies for the treatment of industrial effluents prior to their discharge into the environment. Traditional centralized wastewater treatment systems (advanced oxidation, filtration, membrane filtration, etc.) have been implemented in most of the countries. However, these treatment systems have various limiting factors such as high operational and maintenance cost, energy inefficient, time-consuming, noise and odor production, high greenhouse gas emission and reduced application in rural and remote regions (Chen et al. 2014; Wu et al. 2013). Thus, researchers are looking for cheap and proficient alternative technologies for wastewater treatment. Constructed wetlands (CWs) are an efficient treatment technology suitable for a range of wastewater with fewer infrastructure requirement, minimum operational and maintenance cost, less energy consumption and environment friendly nature (Rai et al. 2013; Vymazal 2014). Moreover, the lifetime of CWs can be extended to several tens of years and with minimal administrative requirements.

Generally, constructed wetlands are considered as artificially designed systems which involve processes close to natural processes but in a controlled environment. They consist of beds filled with appropriate substrate, planted with suitable vegetation and their associated microbial communities for the treatment of wastewater. In the past, constructed wetlands mainly focused on domestic wastewater treatment (Sehar et al. 2015, 2016a) but later their potential was exploited for industrial wastewater (Saeed et al. 2018; Kaushal et al. 2018), agricultural wastewaters (Rozema et al. 2016; Wang et al. 2018), landfill leachate (Madera-Parra and Rios 2017) and stormwater runoff (Guo et al. 2014; Choi et al. 2015). However, no specific criteria are required to choose the appropriate CW system (hybrid, vertical flow or horizontal flow, etc.) for a specific type of wastewater treatment. Several factors such as pollutant load, hydraulic retention time, macrophytes, substrate composition and availability of land should be kept in mind prior to planning a specific CW. Biofilm formed in the roots and rhizomes of macrophytes as well as in the substrate media plays an influential role in biodegradation and biogeochemical transformation of a wide variety of nutrients, organic materials and toxic substances (Vymazal 2010; Sehar et al. 2016b; Sehar and Naz 2016).

While many groups have chronicled recent developments of CWs for industrial wastewater, this review predominantly focuses on the state of knowledge for treating wastewater generated from various food-related industries such as abattoir industry, olive mill wastewater, aquaculture and seafood-processing wastewater, dairy and alcohol fermentation industry. Further, we highlighted some of the challenges during treatment processes that must be tackled in order to make CWs more proficient.

Types of constructed wetland

CWs are classified into various types depending on the kind of vegetation, hydrology and direction of flow path as shown in Fig. 1.

Free water surface (FWS) constructed wetlands

The free water surface (FWS) also termed as surface flow CW comprised of shallow bed cultivated with aquatic macrophytes. Removal of various pollutants is achieved as wastewater to be treated flows through the vegetated beds and substrate media. FWS is extensively applied for the treatment of wastewater from domestic, agricultural and industrial sectors. Table 1 illustrates the application of FWS in treating wastewater from various food-related industries

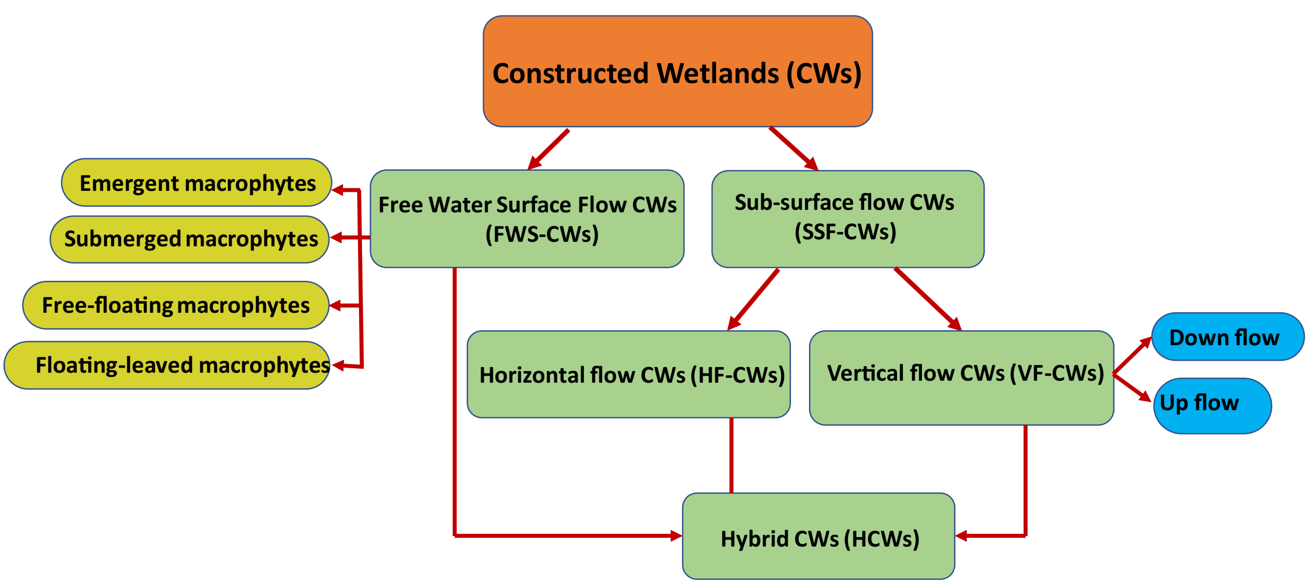

Fig. 1 Classification of constructed wetlands for wastewater treatment

Table 1 Application of various types of constructed wetland for food industry wastewater treatment

Type of wastewater (WW)	Location	Removal performance (%)						Hydraulic loading rate (m^3/days)	Hydraulic retention time (days)	References
		COD	BOD_5	TSS	NO_3–N	NH_4–N	TP			
Free water surface (FWS)										
Dairy WW	Canada	–	99	95	–	94	91	1000	15	Smith et al. (2006)
Potato farm WW	Canada	–	96	99	–	–	90	–	–	Bosak et al. (2016)
Sugar factory WW	Kenya	–	–	76	–	36	29	75	–	Bojcevska and Tonderski (2007)
Dairy WW	Ireland		95.8	–	–	95.2	69.6	3.6–18.5	4	Dunne et al. (2005)
Aquaculture WW	China	–	–	73.2	43.8	14.3	13.1	–	–	Mahmood et al. (2016)
Aquaculture WW	Germany	31	–	67–72	–	–	41–53	1.46–4.37	0.5	Schulz et al. (2004)
Constructed wetlands with horizontal subsurface flow (HF)										
Dairy WW	Italy	91.9	93.7	90.8	–	–	60.6	6.3	–	Mantovi et al. (2003)
Trout farm effluent	Canada	56.	–	84.2	–	–	–	30	4	Quellet-Plamondon et al. (2006)
Trout farm effluent	Germany	67.2	88.7	90.1	−9.7	82.9	40	0.9 L s^{-1}	–	Sindilariu et al. (2007)
Dairy WW	Canada	95.8	–	–	–	95.2	69.6	250	4	Vander Zaag et al. (2008)
Fish farm WW	Canada	83–92	–	76–91	–	–	35–40	30, 60, 90	–	Maltais-Landry et al. (2007)
Dairy WW	Italy	–	92	–	–	17	40	–	–	Gorra et al. (2014)
Winery WW	Spain	54.4	61.3	73.4	–	–	–	24.8	–	De la Varga et al. (2013)
Dairy WW	Australia	–	66	95	–	–	–	–	–	Idris et al. (2012)
Constructed wetlands with vertical subsurface flow (VF)										
Livestock WW	China	–	81.3	77.1	66.6	61.7	48.9	0.4	–	He et al. (2006)
Aquaculture WW	China	–	70.5	81.9	68	61.5	20	–	–	Li et al. (2007)
Oil-rich farm WW	USA	94	96	97	–	–	73	–	5	Travis et al. (2012)
Aquaculture WW	Canada	56	53	39	–	–	58	–	–	Snow et al. (2012)
Piggery and dairy WW	Japan	91–96	94–98	84–97	–	40–85	71–90	1	–	Zhang et al. (2016)
Winery WW	Spain	71.6	67.5	87	–	–	57.6	17.6	–	Serrano et al. (2011)
Livestock WW	China	62.4	–	86.5	–	95	80	0.125	–	Zhu et al. (2012)
Dairy WW	Canada	–	–	–	82	–	58	–	–	Kantawanichkul and Somprasert (2005)
Cheese factory WW	Italy	80.4	80.3	80.3	81.7	39.1	–	0.05	5	Comino et al. (2011)
Hybrid constructed wetlands (HCW)										
Milking parlor WW	Japan	88	89	98	–	–	76	4.5	–	Sharma et al. (2010)
Vinegar production WW	Slovenia	67	66	–	83	–	62	20	15	Justin et al. (2009)
Pig farm WW	Mexico	86.3	–	64.5	–	85	77.9	–	10	Mora-Orozco et al. (2018)
Pig farm WW	Italy	79	–	–	53	63	61	–	0.5	Borin et al. (2013)

(Smith et al. 2006; Bosak et al. 2016; Bojcevska and Tonderski 2007; Dunne et al. 2005; Mahmood et al. 2016; Schulz et al. 2004). Various processes are involved in the removal of contaminants as reported by Vymazal (2013). Removal of suspended and dissolved solids takes place through physical settling, aggregation, filtration and surface adhesion. Organic substances are eliminated through biological degradation under aerobic and anaerobic environments at surface and bottom layers, respectively. Removal of phosphorous is slow and takes place through complexation, adsorption and precipitation. Nitrogen removal is achieved by nitrification/denitrification processes. Oxidation of ammonia takes place with the help of nitrifying bacteria in aerobic areas, whereas nitrate is transformed to nitrous oxide or nitrogen by means of denitrifying bacteria in anaerobic regions. Removal of pathogenic microorganisms in FWS is quite high. However, this removal rate differs significantly depending on initial adhesion of microorganism with sediment or UV radiation in deeper regions (Ghermandi et al. 2007). Heavy metal removal is attained by macrophyte uptake, physical–chemical interactions with the ground and precipitation.

FWS is mostly suitable for polishing of effluents that are already gone through secondary or tertiary treatments via subsurface flow wetlands, activated sludge systems, waste stabilization ponds, etc. Moreover, FWS is quite reliable in the restoration of deteriorated regions as well as reduction in agricultural overflow (Matamoros and Salvado 2012). Further, FWS has various advantages as reported in the literature (Van de Moortel et al. 2009; Vymazal 2011): simple, easy to operate, low operational and maintenance cost, reduced risk of clogging, can attract huge diversity of vectors (fish, insects, reptiles, birds, amphibians and mammals), enhanced organics and solids removal. Contrarily, FWS has certain limitations such as large land requirements, lesser pollutant elimination as compared to subsurface flow wetland, more chances of freezing in winter, risk of odors, mosquito breeding and can be a source of transmitting diseases due to open access to humans and other animals (Lee et al. 2009). A detailed schematic representation of FWS is shown in Fig. 2a.

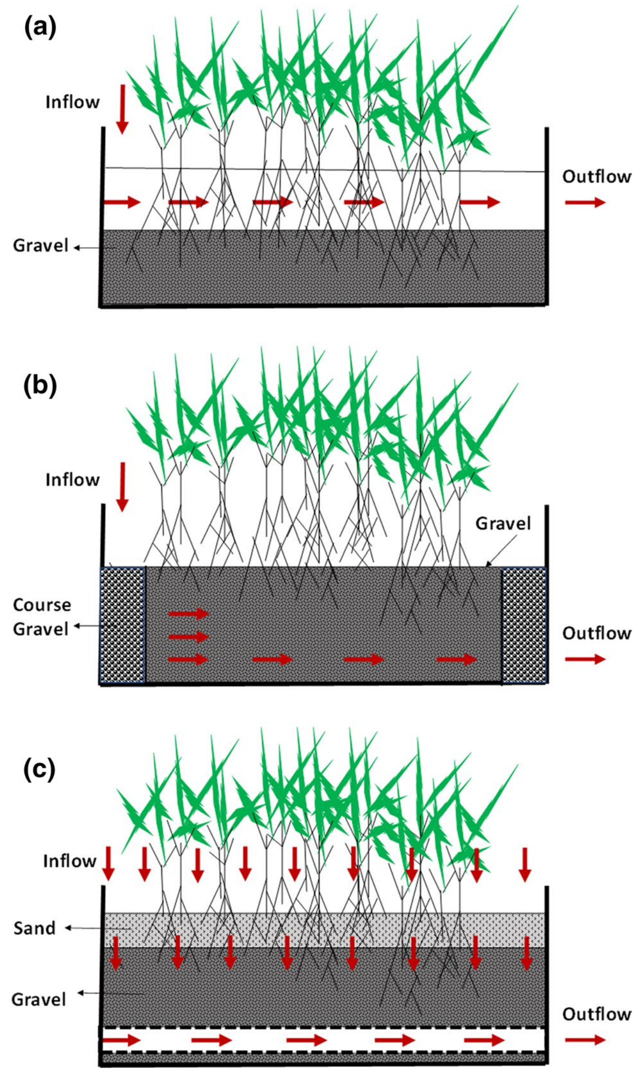

Fig. 2 Schematic layout of different types of constructed wetlands (CWs): **a** free water surface flow CWs, **b** horizontal subsurface flow CWs and **c** vertical subsurface flow CWs

Subsurface flow constructed wetland (SSF-CW)

In subsurface flow constructed wetland (SSF-CW), water to be treated is retained underneath the surface in order to avoid the problem of odor (EPA/US 2000). SSF-CWs comprised of hydraulically isolated filter bed (sands, pea gravel, soil, sandy loams and coarse gravel, etc.) and planted with wide variety of macrophytes. In SSF-CWs, pollutant removal rate is generally high due to thick layers of substrate media that not only serve as filters but also provide microbial attachment sites and subsequent biofilm formation. On the other hand, SSF-CW has certain limitations as reported by Vymazal 2011. In comparison with conventional treatment methodologies, large land area is required for SSF-CW. The accumulation of various metals, phosphorus and some persistent organic substances in the wetland matrix media is another drawback of SSF-CW. Moreover, large quantity of water in SSF-CW is depleted of dissolved oxygen and thus greatly affects the nitrification process.

Subsurface constructed wetlands with horizontal flow (HF)

For subsurface constructed wetland with flow (HF) CW, the wastewater drifts under the bed surface and gradually seeps through wetland fill media in a horizontal manner; thus, wastewater is directly exposed to aerobic and anaerobic regions. Wastewater originated from industries, agriculture, municipal sewage, landfill leachate, etc. have extensively been treated through HF CWs. Table 1 illustrates the application of HF CWs in purification of wastewater generated from various food-related industries (Mantovi et al. 2003; Quellet-Plamondon et al. 2006; Sindilariu et al. 2007; Vander Zaag et al. 2008; Maltais-Landry et al. 2007; Gorra et al. 2014; De la Varga et al. 2013; Idris et al. 2012).

Purification of wastewater in HF system involves chemical, physical and biological processes such as sedimentation, precipitation, filtration, adsorption, plants uptake, biodegradation and nitrogen transformations. Further, HF systems are quite proficient in elimination of pathogens, organic content and total solids (Kadlec 2009), but on the other hand, due to insufficient oxygen transfer capacity, they are less effective for oxidation processes such as aerobic respiration and nitrification (Tyroller et al. 2010; Vymazal 2011). Hence, nitrogen removal takes place through denitrification (as ammonia volatilization process may not occur due to scarcity of oxygen). As a result, elimination of total nitrogen (TN) is quite less. Suspended and dissolved solids are removed through flocculation, physical settling of colloidal and supra-colloidal particulates and adhesion of particulates on biofilm developed on substrate media and roots of macrophytes. Elimination of phosphorus in HF system is usually low which can be uplifted by selecting appropriate substrate matrix with rich sorption tendency. Moreover, some industrial by-products including processed wooden chips, crumpled concrete, steel slags, etc. are highly encouraged for increased phosphorous removal (Vymazal 2014). Schematic of HF CW is presented in Fig. 2b.

Subsurface constructed wetlands with vertical flow (VF)

The subsurface vertical flow wetland systems comprised of 50–100 cm deep fill matrix media (generally sand or gravel) as well as aquatic plants. The wastewater to be treated introduced homogeneously flows through the substrate media in vertical path. In this way, the entire matrix drains thoroughly allowing passage of refill air making oxygen transfer capacity (OTC) much higher in comparison with HF CWs. This transfer of oxygen is attained by different means, i.e., from diluted oxygen already present in wastewater, by diffusion and convection during alternate loading (Torrens et al. 2009). As a result, high OTC levels resulted in enhanced removal of organic content, pathogens (both total and fecal coliforms), suspended solids and nitrogen (nitrate and ammonia) (Vymazal 2010). However, phosphorus removal is not achieved to a great extent in VF (Chang et al. 2012). Worldwide, VF systems are effectively utilized for treating wastewater originated from domestic, municipal, industrial and agricultural sectors. Table 1 shows the utilization of VF system for wastewater treatment generated by food industries (He et al. 2006; Li et al. 2007; Travis et al. 2012; Snow et al. 2012; Zhang et al. 2016; Serrano et al. 2011; Zhu et al. 2012; Kantawanichkul and Somprasert 2005; Comino et al. 2011). VF CW is schematically illustrated in Fig. 2c.

There have been several merits and demerits of VF CWs mentioned in the earlier literature (Cooper 2001; Torrens et al. 2009; Sohair et al. 2012). Less surface area is required for VF CW construction, hence less susceptible for mosquitoes breeding. In addition, there are less chances of clogging in VF system; therefore, relatively improved quality of effluent is generated in comparison with HF system. However, the major demerit of VF CWs is that very restricted or almost no process of denitrification can take place. Besides, they also demand an effective influent distribution system.

Hybrid constructed wetlands (HCW)

In order to attain high contaminant proficiency, several types of wetland systems can be merged on several conformations leading to a combined system termed as "Hybrid Constructed Wetland" (HCW). The most commonly used hybrid wetland systems comprised of vertical and horizontal systems, but there is no compulsion of combing any type of CWs as reported in the previous studies (Vymazal and Kropfelova 2011; Ayaz et al. 2016). Enhanced level of performance is attained in case of HCW as the benefits of different systems complement each other. For example, HF systems are unable to release fully nitrified effluents due to lack of oxygen transfer capacity (OTC), whereas VF systems with enhanced OTC provide much better nitrification but no denitrification takes place in VF which can be provided by HF systems. Therefore, the merits and demerits of each system stabilize each other, thus improving the quality of effluent with less BOD and total nitrogen (TN) level. Moreover, reduced loss of water from the system is another important benefit (Masi and Martinuzzi 2007).

There are different studies in which wastewater from various domestic sources (Abidi et al. 2009; Sehar et al. 2013), chemical industries (Domingos et al. 2007) and wastewater from tanneries (Saeed et al. 2012) was treated using hybrid constructed wetland treatment systems. Table 1 illustrates the application of HCWs for treating wastewater produced from numerous food-related industries (Sharma et al. 2010; Justin et al. 2009; Mora-Orozco et al. 2018; Borin et al. 2013).

Seasonal/climatic variations on treatment efficiency of CWs

The influence of seasonal variation and temperature plays a dominating role in determining pollutant removal efficiencies in CWs. Generally, pollutant removal efficiencies decline in colder climate due to reduced biotic activities. As majority of biological processes are directly related to temperature rise; therefore, warm climate not only favors plant growth but also enhances microbial activity (Zhang et al. 2012). That is why, regions having high humidity level are expected to show better biodegradation of organics and nitrification/denitrification processes. There are various studies, where the effect of temperature on pollutant removal efficiencies was monitored. For example, Truu et al. (2009) described better removal of contaminants in tropical environments within the temperature range of 15–25 °C. Similarly, Vymazal 2005 observed optimum range of nitrification in soil and pure cultures as 30–40 °C and 25–35 °C, respectively. In some reports, improved pollutant efficiencies are also reported by seasonal variation. For example, Song et al. (2009) observed higher COD removal efficiencies in spring and summer season (65.4% and 66.3%) than in autumn and winter (61.1% and 59.4%). Garfí et al. 2012 detected higher elimination of total solids, BOD and ammonia in summer (> 90%) than winter (< 80%). Therefore, CWs showed better performance in hotter climate than the colder one.

There are some strategies which can be implemented to increase the performance efficiency of CWS in colder climate region with extended winter seasons. For instance, longer hydraulic retention times (HRTs), enhanced artificial aeration, less contaminant loading rates, larger as well as deeper beds are highly encouraged to improve the efficiencies of CWs in colder regions (Hijosa-Valsero et al. 2010). Besides, the plantation which has deep penetration roots (such as *Ligustrum obtusifolium*, *Alnus* sp. and *Salix* sp) could be an effective strategy to improve the CWS performance, as it can provide strong oxygen transfer capacity to the plants for longer growing season (Wu et al. 2011). Another effective strategy is the use of insulated material during cold weather to combat the diminished pollutant removal performance. Some of the suggested materials are: bark, pine straw, snow, rock wool, ice, wood chips, polystyrene, greenhouse, etc. (Wallace et al. 2001). A good material must be uniformly spread, have adequate oxygen supply to promote high microbial activity and be significantly degraded (Wu et al. 2011).

Design criteria for CW system

Various parameters such as proper selection of vegetation, media composition and system's hydraulic conditions, viz., hydraulic retention time (HRT) as well as hydraulic loading rate (HLR), are crucial for designing a wetland system to attain maximum removal efficiencies.

1. **Vegetation in CWs**
   Vegetation is a vital parameter in determining the performance of CWs as plant rhizosphere not only provides surface for microbial growth to stimulate microbial activity, but also serves as carbon source (Vymazal and Kropfelova 2011). For enhanced wastewater treatment efficiency, selected plants should have considerable biomass, stem densities, extensive network of roots and roots hair and properly adapted to extreme climatic conditions (Sehar et al. 2013; Vymazal 2013).
2. **Wetland media/substrate**
   A variety of materials are employed as a fill media/substrate of CWs depending upon their availability, cost-effectiveness, hydraulic permissiveness and the ability to absorb a wide variety of pollutants. The frequently used substrates may be from natural source, artificially made fill media or from industrial origin and generally include organic clay, soils sand, gravels, limestone, vermiculite, slag, dolomite, shell, wollastonite, crushed stones, lightweight aggregate (LWA), calcite, marble, Zeolite and Bauxite, fly ash, bentonite and activated carbon (Sehar et al. 2013, 2016a, b, b; Yan and Xu 2014). The fill matrix media not only provide surface for microorganisms' attachment and growth of macrophyte but also help in precipitation and adsorption of various chemicals and metals from wastewaters (Ju et al. 2014). Calheiros et al. (2009) used two different varieties of expanded clay aggregates and reported high removal of COD and BOD_5. Different reports suggested a wide range of particles size used in media matrix; however, most of times, the particle sizes used in HF CWs are 8–16 mm as reported by IWA (2000). On the other hand, Garcia and Corzo (2008) obtained better performance by using homogeneous particles of size 5–8 mm and their results suggest that finer particles can offer greater surface area for microbial adhesion and biofilm formation. However, fine material may increase the risk of clogging the fill media.
3. **Effect of hydraulic conditions**
   Hydraulic conditions are also influential in determining microbial community composition, biogeochemical processes and resulting pollutant removal efficiency in CWs. Higher hydraulic loading rate (HLR) allows faster passage of wastewater through the substrate resulting in reduced optimum contact time. On the other hand, longer HRT favors in establishing more contact time among substrate, plant rhizosphere and inhabiting microbial community; and ultimately enhanced pollutant removal rate is achieved (Yan and Xu 2014). Zhang et al. (2012) evaluated the treatment efficiency of pig breeding farm under different HRTs of 1, 2, 4 and 8 days in a vertical flow wetland system. They obtained high pollutant removal efficiency by increasing HRT to 8 days than lower HRT times.

Generally, during elevated loading rate or less retention time, wastewater is forced to move quickly toward the outlet, resulting in less pollutant removal rate due to decreased interaction of rhizosphere and inhabiting microbial communities with wastewater. Cui et al. (2010) noticed less removal of ammonium (65–60%) and total nitrogen (30–20%) by increasing loading rate from 7 to 21 cm day^{-1} in VF CWs for treating domestic wastewater. In contrast, Stefanakis and Tsihrintzis (2012) reported improved organic and nitrogen removal by elevating loading rates in VF CWs for treating synthetic wastewater.

Wastewater from food industries

Different types of food industries are generating huge quantity of wastewater that varies significantly with each other. In general, wastewater from these food industries is high in organic content, suspended and dissolved solids, ammonia and other contaminants, therefore requires additional treatment before being treated through constructed wetland systems. Table 2 describes composition of wastewater from various food industries (Chowdhury et al. 2010; De Sena et al. 2008; Gannoun et al. 2009; Anastasiou et al. 2009; Guven et al. 2009; Demirel et al. 2005; Coskun et al. 2010; Jail et al. 2010).

Abattoir industry/slaughterhouse effluent

Abattoirs as well as meat-processing industries are generating huge volume of wastewater with higher contents of both soluble and insoluble biodegradable organic substances, thus posing serious threats to the environment. Abattoirs wastewater is also enriched with high concentrations (approximately 1000 mg L^{-1}) of oil and grease (Gannoun et al. 2009). Moreover, wastewaters from slaughterhouses also contain elevated amounts of pathogenic as well as non-pathogenic microorganisms, animal's blood, nutrients, heavy metals, detergents, disinfectants and cleaning agents (Debik and Coskun 2009). Contaminants level in abattoir wastewater may vary depending on number, type and size of animals. Furthermore, slaughterhouse effluent is also influenced by water consumption. The discharge of wastewater from slaughterhouses without any appropriate treatment has been documented to not only pollute water bodies, but also disturb natural ecosystem (Sunder and Satyanarayan 2013). Therefore, researchers focus on abattoir wastewater treatment through different biological means including constructed wetland, aerobic digestion, etc. in order to reduce its environmental impacts.

In Canada, Goulet and Sérodes (2000) reported purification of abattoir wastewater through FWS wetland system vegetated with native *Typha* sp. In their study, they used septic tank (750 m^3) and two parallel units (accumulative surface area 1420 m^2). The reported overall removal efficiencies were 85%, 95%, 54%, 74% and 66% for BOD_5, solids, NH_4–N, TP and TKN, respectively. Another study was conducted in Mexico to treat the similar type of wastewater with high organic content by HF CW (Poggi-Varaldo et al. 2002). The treatment scheme comprised of a storage tank and two successive units (combined surface area 1144 m^2) cultivated with native vegetation, *Typha latifolia* and *Phragmites australis*. The overall removal efficiency for COD, BOD_5, TSS and Org-N was recorded as 74, 77,

Table 2 Concentrations of major pollutants in wastewater from various food industries reported in the literature

Type of wastewater	Source of pollutant	Nature of contaminant (mg L^{-1})						References
		COD	BOD_5	TSS	TKN	TP	NH_4–N	
Seafood processing	Seafood processing	325–90,000	40–78,000	15–10,000	77–3000	10–390	1–860	Chowdhury et al. (2010)
Abattoir	Meat processing	400–11,200	600–4600	200–9300	530–810	15–50	65–740	De Sena et al. (2008) and Gannoun et al. (2009)
Winery	Washing equipment and bottles and for cooling	500–45,000	500–40,000	1000–7300	–	5–77	0.001–2	Anastasiou et al. (2009)
Sugar mill	Crushing and grinding of sugar	3500–10,000	4000–7000	350	53	53	4.8	Guven et al. (2009)
Dairy/cheese factory	Parlor milk processing and cleaning	2000–95,000	1400–50,000	20–22,000	14–5600	8–540	20–22,000	Demirel et al. (2005)
Olive oil mill	Olive oil extraction	37,000–318,000	10,000–150,000	6000–83,700	1540	410–840	–	Coskun et al. (2010) and Jail et al. (2010)

44 and 48%, respectively. Moreover, total and fecal coliforms were reduced in 5.0 and 5.5 log units.

Gutierrez-Sarabia et al. (2004) monitored the treatment efficiency of pilot-scale SSF-CW for slaughterhouse effluent in Mexico. A satisfactory level of contaminant removal (BOD_5—91%, COD—89% and TSS—85%) was attained. Reasonable amount of organic nitrogen (80%) was removed; however, ammonium removal rate was quite low, i.e., only 9%. In Lithuania, wastewater from meat-processing industry was treated through HF CW (total surface area 1880 m^2) cultivated with *P. australis* (Gasiunas et al. 2005). The pretreatment cell comprises of 500 m^3 septic tank. Visible decrease in BOD_5, TN and TP amount was noticed in the effluent as shown in Fig. 3.

In Canada, abattoir wastewater treatment was carried out by establishing a two-celled surface flow CW (58.5 m^2 area) planted with *T. latifolia* (Carreau et al. 2012). Their calculations revealed that on an average, discharge produced by slaughtering an animal contained 0.75 m^3 of wastewater with influx rate of 124 m^3 annually. The residence period in CW during the productive season was estimated to be 111 days through a tracer test suggesting high operative volume (89%) of the system. Generally, more deduction was observed during the productive climate in comparison with the non-productive climate.

Olive mill wastewater (OMWW)

Olive oil extraction is an agro-industry and contributes to an important part in the economy of European Union, particularly in Mediterranean countries such as Greece, Italy, Spain, Tunisia, Israel, Cyprus, Jordan and Portugal. However, its production is creating serious environmental concerns as it generates huge amount of wastewaters as well as solid wastes. The chemical composition of OMWW keeps on fluctuating due to various factors, viz., the age and type of olive tree, climate and cultivation process, the use of fertilizers and pesticides, extent of fruit ripening and the applied extraction procedures (Yay et al. 2012).

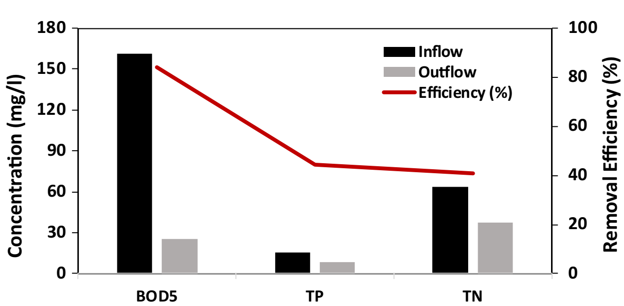

Fig. 3 Treatment performance of HF CW for the treatment of abattoir wastewater at Lithuania. Data from Gasiunas et al. (2005)

Olive mill wastewater is mainly dark brown in color with pungent smell, high turbidity, less pH, elevated levels of total suspended solids ranging from 6 to 70 g L^{-1} and organic content in the range of 30–318 g L^{-1} (Kiliç et al. 2013; Amor et al. 2015). Besides, OMWW also has various complex toxic and non-biodegradable substances including phenolic compounds, tannins, pectin, organic acids, polysaccharides, sugars, proteins, lipids, etc. The presence of these persistent and toxic substances leads to serious environmental issues such as foul odors, endangered aquatic life, affects soil quality and saturation, phytotoxicity and eutrophication of surface as well as ground waters (Yay et al. 2012). Various treatment approaches such as stabilization ponds, thermal concentration, electrooxidation (Un et al. 2008), nanofiltration, reverse osmosis (Coskun et al. 2010), aerobic and/or anaerobic treatment (Ammary 2005) and electro-coagulation (Un et al. 2006) have been utilized. However, most approaches are not only costly but also produced sludge or other by-products that need further treatments. Constructed wetland has been successfully utilized for OMW treatment in various countries. We present some of the reports that depict OMW treatment in an efficient way through constructed wetlands as follows.

In Turkey, Yalcuk et al. (2010) studied the proficiency of large-scale VF wetland for treating OMWW with higher organic content. Different types of vegetation, viz., *T. latifolia* and *Cyperus alternifolius*, were cultivated and their treatment efficiency was related to unplanted control system. Their results suggested that overall *T. latifolia* presented improved the efficiency for pollutant removal (COD 73.46%, ammonia 49.06%, ortho-phosphate 95.43%) than the unplanted control and *C. alternifolius*. This improved removal efficiency can be attributed to the thick and dense networks of roots and root hair structure of *T. latifolia* that not only increase the permeability of dissolved oxygen but also support rich and diverse biofilm that helps in the disposal of nitrogen. Thus, aerobic environment was maintained in the rhizosphere that may favor organic decomposition, enhance nitrification and gaseous loss of nitrogen through denitrification.

In another study, Grafias et al. (2010) narrated the performance of olive pomace leachate (OPL) through a hybrid process, viz., VF CW followed by electrochemical oxidation. *Phragmites australis* was planted in wetland units and loaded with 15 g COD m^{-2} day^{-1} with 3 days hydraulic retention time. After treatment through wetland, average COD removal of 86% and 77% reduction in color was achieved. Further polishing of the CW effluent through anodic electrochemical oxidation was accounted to be 95% and 94% for COD and color, respectively. On the other hand, the reverse scheme generated 40% less removal, i.e., only 81% and 58% for COD removal and color reduction, respectively.

Herouvim et al. (2011) evaluated treatment efficiency of OMWW in pilot-scale VF CW in Greece. CW system comprised of four units filled with porous matrix media (cobbles, gravel and sand) and planted with common reeds. Overall, CW system with vegetation was quite effective in treating various high-loaded pollutants such as TKN, COD, phenols and ortho-phosphate with removal rates of removal efficiency of 75%, 70%, 70% and 87%, respectively. On the other hand, no prominent change in removal of ortho-phosphate was noticed in both planted and unplanted units.

The performance of two FWS CWs (with and without effluent recirculation) for OMWW was assessed by Kapellakis et al. (2012) in Greece. The area of both CWs was 45.5 m^2, cultivated with *P. australis* and occupied with gravels. Their results suggested that CW with effluent recirculation showed superior performance for COD, TKN, TP, TSS as 90%, 87%, 85% and 98%, respectively, as compared to FWS without recirculation (COD 80%, TKN 78%, TP 80 and TSS 83%).

Michailides et al. (2015) demonstrated the efficiency of a pilot-scale FWS CW cultivated with *P. australis*. The treatment system was evaluated for pre-treated olive mill wastewater. Results showed that FWS CW efficiently reduced the concentrations of COD (27,400–3960 mg L^{-1}), TKN (770–45 mg L^{-1}), phenols (4800–656 mg L^{-1}) and orthophosphate contents (191–13 mg L^{-1}) with removal rates of 94% (COD), 98% (TKN), 95% (phenols), 95% (orthophosphates) after 60 days residence time period. Gikas et al. (2018) investigated the performance of two large-scale hybrid natural systems. The first HCW system is composed of two open tanks, one VF and one FWS, while other systems consisted of two open tanks and one FWS CW. Their results are presented in Table 3.

Aquaculture and seafood-processing industry

Over the past few years, aquaculture industry is gaining much attention due to large consumption of seafood worldwide and its contribution to the economic growth. Seafood-processing wastewater is typically high in dissolved and suspended solids, colloidal particles, nutrients (salts and oils) and ammonia nitrogen (Konnerup et al. 2011). Besides, it has high organic content due to contamination with blood, fish heads and intestinal remains (Schwitzguébel and Wang 2007).

When this high-strength wastewater is released without treatment, it is equally dangerous to the ecosystem as well as environment including eutrophication, depletion of dissolved oxygen, generation of obnoxious odor and aquatic toxicity (Thériault et al. 2007; Jamieson et al. 2009). Several seawater-processing technologies such as rotating biological contactors, trickling filters and fluidized bed reactor (Zachritz et al. 2008; Zhang et al. 2010) have been implemented, but they did not meet the strict effluent criteria set by water authorities under intensive production conditions (Sindilariu et al. 2007). Constructed wetlands with additional benefit of both mechanical and biological effluent treatments prove to be the most competent, budget and eco-friendly choice for the treatment of saline runoff and aquaculture wastewater by careful selection of facultative or obligate halophytes (Calheiros et al. 2012; Lymbery et al. 2013). Some of the previously reported studies which highlighted the use of constructed wetlands for the treatment of aquaculture wastewater are summarized in Table 4 (Sindilariu et al. 2007, 2008; Li et al. 2007; Zachritz et al. 2008; Lin et al. 2005; Shi et al. 2011; Klemencic and Bulc 2015).

Zhang et al. (2011) established recirculating aquaculture system (RAS) comprising of a pond, two parallel HF CWs and recirculating ponds. The entire system was designed for fish farming, and the performance was monitored for 2 years. The wetland was cultivated with mixed vegetation, viz., *Canna indica, Acorus calamus, Iris tectorum, Cyperus papyrus* and *Thalia dealbata*. The results showed that the amount of dissolved oxygen (DO), pH, suspended solids, nutrients and organic matter dropped significantly in 2 years under 600 mm day^{-1} HLR as illustrated in Table 5. Due to the recirculation and removal of pollutants, the water quality was enhanced that favors fish production.

Webb et al. (2013) monitored the removal efficiency of small-scale SSF-CWs in eliminating nitrogen from aquaculture wastewater that is released from recirculating aquaculture system (RAS). The results showed that planted beds were more efficient in eliminating 34–73% of influent (concentration 62 mmol Nm^{-2} day^{-1})

Table 3 Treatment performance of hybrid pilot-scale natural systems treating olive mill wastewater in Greece. Data from Gikas et al. (2018)

Parameters (mg L^{-1})	First hybrid system			Second hybrid system		
	Influent	Effluent	Removal rate (%)	Influent	Effluent	Removal rate (%)
COD	49,645	22,784	41.1	23,322	11,715	49.4
TSS	1114	535	39.6	2749	581	72
TKN	170	95	27	329	242	26.9
Phenol	4883	1947	56.5	1832	891	51.1

First hybrid system: combination of VF and FWS CW; second hybrid system: FWS

Table 4 Comparative analysis of different types of constructed wetlands used to treat wastewaters from various recirculating aquaculture systems

Location	CW type	Removal efficiency (%)								References
		BOD	COD	TSS	TP	$PO4_3^-$	TN	NH_4–N	NO_3–N	
Taiwan	FWS–SF	37–54	–	55–66	–	–	–	64–66	–	Lin et al. (2005)
China	VF	70.5	–	81.9	–	20.0	–	61.5	68.0	Li et al. (2007)
USA	SSF	–	–	67.2	–	–	–	4.50	40.6	Zachritz et al. (2008)
Germany	HF	36.9	24.3	34.8	38.3	− 1.0	− 2.0	–	− 5.0	Sindilariu et al. (2007)
Germany	HF	71.6	54.8	84.7	44.0	− 158.5	5.7	–	− 8.3	Sindilariu et al. (2008)
China	VF–HF	–	27.0	66.0	24.0	–	67.0	–	59.0	Shi et al. (2011)
Slovenia	VF	49.0	35.0	57.0	25.0	− 53.0	31.0	42.0	− 79.0	Klemencic and Bulc (2015)

Table 5 Removal of contaminants by the horizontal subsurface flow CWs within 2 years' time period. Data from Zhang et al. (2011)

Parameters (mg L^{-1})	First year of treatment			Second year of treatment		
	Inlet (mg L^{-1})	Outlet (mg L^{-1}l)	Removal rate (%)	Inlet (mg L^{-1})	Outlet (mg L^{-1})	Removal rate (%)
DO	10.90	2.74		2.970	0.97	
TSS	53.2	9.30	82.0	59.70	14.2	75.4
COD	9.40	4.70	50.0	10.50	4.70	52.0
NO_2^-–N	0.032	0.010	60.7	0.064	0.016	59.8
NO_3^-–N	0.08	0.04	43.8	0.08	0.06	16.1
TN	1.92	1.16	34.6	2.73	1.73	35.6
TP	0.39	0.23	40.4	0.44	0.24	46.2

dissolved inorganic nitrogen in comparison with − 1 to 41% (23.0 mmol Nm^{-2} day^{-1}) in unplanted control beds. On the other hand, no significant removal for dissolved inorganic phosphorous was observed in both beds.

Milk and cheese industry

Dairy industry is gaining global recognition due to its rising demand as well as its nutritional constituents. Sidewise, dairy production facilities are generating large quantity of wastewater (approximately 0.5–10 L) from roughly every 1 L of milk that may result in environmental pollution if not correctly handled (Tawfik et al. 2008). Wastewater from dairy industry is generally of high strength with elevated levels of organic matter (BOD 0.8–2.5 kg/metric ton of milk; COD 80 mg L^{-1}), total suspended solids (10^2–10^3 ppm) (Amini et al. 2013; Merlin et al. 2012), lipids, mineral salts, soluble proteins and pH values ranging from 3.5 to 11 (Demirel et al. 2005). Moreover, there are some reports showing traces of heavy metals in dairy wastewater originating from control laboratories (Chatzipaschali and Stamatis 2012; Perna et al. 2013). Besides milk, dairy wastewater may have various other components such as cream, cheese whey, yogurt starter culture, stabilizers, sterilizers, caustic cleaning agents, sanitizers and detergents (Liu and Haynes 2011). In cheese-making plants, the greenish-yellow and/or whitish liquid generated after the precipitation and elimination of milk proteins, viz., casein, is termed as cheese whey wastewater.

Due to the complex nature of pollutants in dairy wastewater, it is important to treat these dairy effluents for environmental conservation as well as for reuse of water in various industrial practices. In the past, there have been several studies focusing on the biological treatment of milking parlor effluents (Hill et al. 2003; Mantovi et al. 2003) and cheese producing industries (Wallace 2002; Khalil et al. 2005) through constructed wetland systems. In Italy, Gorra et al. (2007) established HF CW to treat wastewater from cheese production plant. A mixture of different fill media, viz., zeolite, gravel, magnetite, ceramic wastes in grinded form, and soil loaded with marble were used. Their results showed that HF wetland proved to be quite proficient in reducing the average influent concentrations of BOD_5 (from 839 to 130 mg L^{-1}), organic nitrogen (from 176 to 133 mg L^{-1}) and NH_4–N concentrations (from 22.7 to 16.6 mg L^{-1}). Another study was carried out in Italy for treating wastewater from mountain cheese factory (Comino et al. 2011). The entire treatment system comprised of two parallel vertical flow units and a horizontal flow unit, with total surface area of 180 m^2 each. *Phragmites australis* was planted in all wetlands. The entire treatment system was planned to process organic load (BOD_5 24 g m^{-2} day^{-1}) which was two times less than actual average organic loading. Their results suggested that due to high BOD_5 loading rate, treated wastewater did not fulfill Italian effluent limits and the treatment efficiency recorded for TSS, BOD_5, COD, TP, TN was 60, 55, 72, 37 and 50%, respectively.

Idris et al. (2012) assessed the performance of two gravel-based HF CWs for dairy wastewater in Australia. Different plant species, viz., *Arundo donax* and *P. australis*, were cultivated, and their removal rates were compared with unplanted control system. The system was fed with HLR of 3.75 cm day^{-1}. No significant change ($p > 0.007$) was recorded in the removal rates of vegetated and non-vegetated systems. Besides, both the plants proved equally good in the removal of various parameters, viz., BOD, SS and TN removal amounted to be 69, 95 and 26% for *A. donax* and 62, 97 and 26% for *P. australis*, respectively. This slight increase in the removal efficiency of HF CW planted with *Arundo donax* was due to the increased biomass over the ground (37 ± 7.2 kg wet weight) as compared to *P. australis* (11 ± 1.4 kg wet weight). Thus, *Arundo donax* could be a better choice for dairy wastewater treatment and can be utilized as a source of secondary income for farmers as it produced large amount of biomass (dry weight) approximately 179 tons ha^{-1} $year^{-1}$.

Kato et al. (2013) designed multistage HCW systems for removing concentrated dairy wastewater in cold weather (5 and 8 °C) region of northern Japan. Individual systems were monitored over a period of 4.6 years, 3.6 years and 2 years, respectively. System configuration, surface areas, overall HLRs, influent and effluent loading rates of three wetland systems are shown in Table 6. Authors reported that multistage wetland was proficient in eliminating 93–96% COD. Reduction in TN varied among systems with removal rate of 63–89%. Moreover, all the wetlands were proficient enough to remove a reasonable amount of NH_4–N (62–82%) and total phosphorus 70–88%.

Recently, Schierano et al. (2018) inspected the performance of HF CWs for the tertiary treatment of dairy effluent in Argentina. Ten microcosm-scale HF wetlands were established, out of which half were cultivated with *Typha domingensis* and another half with *P. australis*. In all systems, lightweight expanded clay aggregate (LECA) 10/20 was considered as fill media. The systems were operated under 7 days HRT with hydraulic load of 1000 mm day^{-1}. Their results showed that HF CW planted with both types of vegetation showed higher removal efficiency for COD (75%) as well as for ammonium and nitrite (over 96%). However, no promising difference in the elimination of nitrate was detected in both types of vegetation, while significant difference in the removal of phosphorus (88.5%) was recorded for *T. domingensis* in comparison with 71.6% for *P. australis*. Plant uptake could be the possible reason for maximum phosphorous removal as *T. domingensis* forms dense biomass over the surface as compared to *P. australis* that in turn may also contribute to elevated phosphorus levels in tissues.

Alcohol fermentation industry

Alcohol fermentation industry generates huge volume of wastewater and solid wastes into receiving water bodies, ground and above ground water that have been known to cause environmental pollution and disturb the natural

Table 6 Systems configuration, surface area, HLRs, influent and effluent loading rates of three hybrid constructed wetlands to treat dairy wastewater from three farms in Japan. Data from Kato et al. (2013)

System configuration	Dairy farm 1 VF–VF–HF–VF	Dairy farm 2 VF–VF–HF	Dairy farm 3 VF–VF–HF–VF
Surface area (m^2)	1174	656	1789
HLR (cm day^{-1})	2.0	0.7	0.9
Influent concentration (mg L^{-1})			
COD	2382	3973	5002
TN	100	160	198
NH_4–N	30.5	70	38
TP	19.8	25.2	37.6
Influent loads (g m^{-2} day^{-1})			
COD	49.9	29.2	42.7
TN	2.08	1.18	1.69
NH_4–N	24.7	32	22
TP	0.40	0.19	0.32
Removed loads (g m^{-2} day^{-1})			
COD	46.4	26.6	40.2
TN	1.41	0.35	1.43
NH_4–N	20.7	15	15
TP	0.25	0.13	0.27

ecosystem. Alcohol fermentation industry can be classified into three main groups, viz., wine manufacture, brewing and distilling.

Winery

Wine is considered among the most consumed beverages worldwide with annual production of around 250 million hector liters (Masi et al. 2015). Wineries generate huge amount of wastewater during the various steps of grapes processing including vintage and racking as well as from cleaning of fermentation chambers, bottling and another winery apparatus (Anastasiou et al. 2009). All these steps require proper treatment to evade hazardous environmental effects on receiving streams. The chemical nature of wastewater generated from wineries keeps on varying due to several factors, viz., type of wine produced (red and white), adopted industrial processes and seasonal variation. In addition, winery wastewater contains high organic content and suspended solids. These organics largely comprised of elevated levels of soluble sugars (fructose and glucose), 25 different types of alcohols including ethanol and glycerol, 26 tannins, lignins, acids such as acetic, lactic and tartaric acid (Agustina et al. 2008; Serrano et al. 2011). Moreover, pH of winery wastewater lies in the range of 3.5–7, nitrogen and phosphorous level ranged from 8 to 36 mg L^{-1} and 1.5 to 20 mg L^{-1}, respectively (Bories et al. 2007).

Different physical and chemical technologies have been implemented to treat winery wastewater including photocatalytic oxidation (Anastasiou et al. 2009), activated sludge (Petruccioli et al. 2002), etc. However, these traditional treatment systems failed to efficiently handle this complex winery effluent due to the fluctuation in its composition and organic load and type of end-product, e.g., red and white wine (Valderrama et al. 2012). Constructed wetland systems were introduced in the early 1990s in USA for winery wastewater treatment, and gradually this technology was adopted worldwide due to ease in operation, less energy consumption, low cost and enhanced removal efficiencies (Vymazal 2009).

High organic loading rate in winery wastewater often leads to clogging in CWs that may results in the reduction in oxygen penetration into the growth media, thus affecting the proficiency of CWs system (Grismer et al. 2003). Therefore, pre-treatment is often suggested by the application of either septic or Imhoff tanks, aerobic/anaerobic digester or aeration followed by horizontal/vertical flow subsurface flow wetland. However, in the case of bigger wineries, combination of wetland systems or combination of wetland systems with other technologies such as anaerobic digestion or aerobic biological systems is suggested that serves the same purpose of pre-treatment (Masi et al. 2015). Some of the cases of the above-mentioned combinations are reviewed briefly.

A pilot-scale HCW was established in Spain for winery wastewater treatment (Serrano et al. 2011). The system comprised of up-flow sludge bed digester (for pre-treatment) followed by a VF CW and three HF CWs in parallel. VF CW was cultivated with *P. australis* and granite gravel (particle size 3–6 mm) as substrate, while HF CWs were cultivated with *Juncus effusus* and with washed gravels (particle size 6–12 mm) as substrate. The entire treatment system was functioned at average HLR of 19.5 mm day^{-1}. Authors reported that hydrolytic up-flow sludge bed digester helped to prevent clogging, while the combination of VF + HF CW managed to reduce organic content, i.e., COD and BOD by 73 and 74%, respectively. Besides, other pollutants such as TSS, TKN, NH_3-N and phosphates were also reduced as depicted in Fig. 4.

A pilot-scale HCW was established in Pontevedra (Northwest Spain) to treat medium-sized winery effluent (de la Varga et al. 2013). The system comprised of

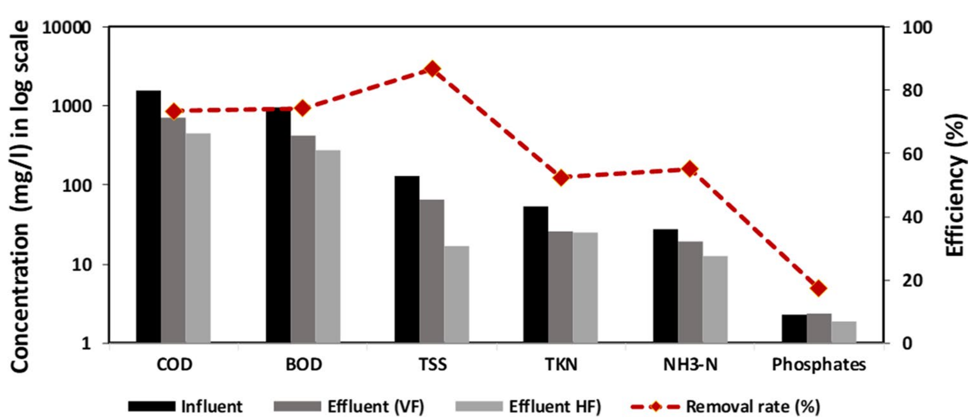

Fig. 4 Removal efficiency of winery wastewater through hybrid constructed wetland. Data from Serrano et al. (2011)

combination of vertical flow (50 m^2), three horizontal flow units (100 m^2 each) and an anaerobic digester (volume 6 m^3). The treatment system was monitored for more than 2 years with major focus on suspended solids accumulation and hydraulic conductivity. Anaerobic digester served as a pre-treatment unit and helped in reducing loading rate of suspended solids by 76%, dropping the elevated levels of influent suspended solids from 520 to 129 mg L^{-1} which after treatment through CW further dropped to 17 mg L^{-1}. Further, satisfactory level of treatment efficiency was reported for COD and BOD that amounted to be 95.6 and 78.7%, respectively. As anaerobic digesters were supposed to prevent the issue of clogging, hybrid CW did not face this problem for the next 2 years. After 2.2 functional years, accumulation of solids reached 4.6 kg TSS/m^{-2} and the hydraulic conductivity reached to 134 ± 22 m day^{-1}. Thus, the combination of anaerobic digester with CW not only was proven efficient for long-term operation of CW by avoiding clogging issues but also met the basic standard of low operational and maintenance cost as well as sustainability.

Breweries

Brewery industry is generating huge amount of wastewater from various processing steps of beer production as well as from discharged residual beer. The composition of brewery effluent depends on various factors such as difference in fermentation and filtration processes, wort preparation, management of raw material and packaging. The amount of wastewater discharged from brewery industry is dependent on the consumption of water during the entire process of beer production. Generally, 4.73 m^3 of water is required for 1 m^3 volume of produced beer (Brito et al. 2007) which produce 1 L of beer and approximately 3–10 L of wastewater (Olajire 2012). The characteristic brewery effluent has high levels of organics, suspended solids and temperature ranging from 25 to 38 °C, low pH (between 3 and 4) and low heavy metal concentrations (Vymazal 2014). The high organic content is because of dissolved carbohydrates, while high suspended solids can be ascribed to malt, spent maize, yeasts, slurry diatomaceous earth (DE) and packing materials (Driessen and Vereijken 2003). The disposal of such elevated concentration of organics in brewery wastewater into water bodies can have severe problems for aquatic biota by depleting the oxygen level (Rashed 2011). Besides, wastewater with high levels of suspended solids decreases the availability of light to photosynthetic organisms inhabiting water bodies, thus making living environment unsuitable for many invertebrates and serious physiological and neurological issues for humans.

To date, very limited literature is accessible for brewery effluent. Common practice was to simply release brewery wastewater into the water bodies that lead to environmental pollution. Therefore, to satisfy increasing pressure from environmental protection legislation, brewing industries started to implement a pre-treatment option before being directly disposed to the environment. In this regard, brewery effluent was pre-treated through physical, chemical and biological means to eradicate maximum particulate and colloidal contaminants before being discharged into waterways or municipal sewer systems. Among biological treatments, CWs are described as an appropriate option for the treatment of brewery effluent (Simate et al. 2011). However, very little data are available for the application of CWs in treating brewery wastewater. Reason behind this can be attributed to large land area demand, huge water and energy consumption, generation of wastewater, solid wastes and their by-products as well as gas emission to air. Crous and Britz (2010) estimated the proficiency of a large-scale HF CW for Ibhayi Brewery effluent in South Africa. Although anaerobic digester and joined algal pond were part of treatment system and operational, they did not fulfill the discharge limits according to South African standards, and therefore, CW was connected to the system for enhancing the treatment of brewery effluent. For this purpose, four horizontal flow CWs with accumulative surface area of 56 m^2 were used and cultivated with *Typha capensis* and *P. australis.* Their results suggested that the addition of horizontal flow CW successfully helped in reducing the monitored pollutants (COD, NH_3^+, NO_2^- and phosphate as 75, 3 15 and 10 mg L^{-1}) below discharge limits.

Distillery

Distilleries produce alcoholic beverages by using variety of agro-products such as sugarcane juice, sugarcane molasses, sugar beet molasses and wine. However, during processing of these alcoholic beverages, distilleries generate large amount of residual liquid waste known as "stillage" or "spent wash" which is a serious risk to the environment and water bodies. Distillery wastewater is characterized by its acidic nature, dark brown color because of the occurrence of melanoidin, rise in temperature, elevated ash and organic content, i.e., BOD 40,000–50,000 mg L^{-1} and COD 10,000–125,000 mg L^{-1} (Strong and Burgess 2008; Acharya et al. 2011). Untreated distillery wastewater may damage aquatic system and cause environmental pollution. Besides, it can also affect soil fertility. Therefore, different treatment technologies have been adapted for safe disposal of distillery effluent to protect the environment. Among biological methods, constructed wetland has been extensively applied for the treatment of spent wash in the last two decades. Large-scale HF CW was constructed in India for treating distillery wastewater (Billore et al. 2001). The entire system comprised of a pre-treatment unit and four HF CWs (total surface area 364 m^2). The first two units were unplanted and serve as preliminary treatment, while the last two treatment units were cultivated with native vegetation, *T. latifolia* and *P. karka*, respectively. Their preliminary results showed that despite traditional secondary treatment, the concentration of organic content in distillery effluent was quite high, i.e., BOD_5 2540 mg L^{-1} and COD 13,866 mg L^{-1}, respectively. Overall percentage removal for entire system was found to be 84, 64%, 79% and 59% for BOD_5, COD, phosphate and total nitrogen, respectively.

In Mexico, the proficiency of HF CW was monitored for the treatment of diluted sugarcane molasses spent wash (Olguín et al. 2008). Volcanic gravel was used as fill media, cultivated with *Pontederia sagittate* and operated at 2.5- and 5-days HRT. The influent concentration of organics even after dilution (1:15 with tap water) was quite high, i.e., 534 mg L^{-1} and 1181 mg L^{-1} for BOD_5 and COD, respectively. They reported almost similar types of results at both HRTs, except for NH_4–N and BOD_5, where elimination rate was much improved in 5 days HRT in comparison with 2.5 days. The HF system was efficient enough to remove organics and majority of nutrients depending on the HRT in the following range: 80.2–80.6%, 73.4–76.1%, 56–58.7%, 2–10% and 68.6–69.5% for COD, TKN, NO_3–N, NH_4–N and SO_4^{2-}, respectively. The authors did not detect any removal of phosphate and potassium; however, the generated effluent was safe enough to be fed to sugarcane fields for irrigation purposes.

Challenges, operational strategies and future recommendations

CWs are considered as a reliable technology worldwide for a wide variety of wastewater treatment from industrial sectors. The performance of CWs can be greatly enhanced by considering its design and operational conditions (seasonal variation, hydraulic loading and retention time, selection of macrophytes and substrate media, etc.). Some of the important characteristics of effluents from food industry that may create problems during conventional CWs treatment are discussed as follows. Further, different operational strategies to cope with these issues along with future recommendations will be addressed.

1. Many of the food industries such as dairy, distillery, winery, abattoir and olive mill industry are generating huge amount of wastewater during various production processes with high organic content (BOD and COD), dissolved and suspended solids. The previous literature showed that direct feeding of such high organic loading rate into CWs not only influenced the removal rates and hydraulics of system but also had a negative impact on the wetland vegetation characterized by slower plant growth or early wilting of the wetland plants (Zingelwa and Wooldridge 2009; Singh et al. 2010). To resolves this serious issue of high organic content, direct feeding of raw wastewater should be avoided in large-sized industries, although some small-/moderate-sized manufacturers would be unable to follow this practice particularly in rural areas. Besides, the negative effects of high organic loading can be reduced through preliminary aerobic/anaerobic pre-treatments by introducing anaerobic digesters (UASB and HUSB). In addition, the influent concentration can be diluted through effluent recirculation. Furthermore, the use of HF CWs can be a better choice as they have strong buffering capacity for elevated organic loading rate.
2. Clogging of substrate is a significant issue in CWs while treating wastewater generated primarily from olive mill industry, milk processing, slaughterhouse and wineries. Substrate clogging results in sudden failure of the wetland system by reducing infiltration of oxygen into the growth media due to solids accumulation and ultimately biomass growth (Nivala et al. 2012). In this situation, proper means of artificial aeration should be adopted to increase oxygen transfer rates in wetland layers that speed up aerobic microbial activity in breakdown of complex contaminants. Further, pre-treatment of influent may also help in delaying clogging process.
3. The wastewater discharge from olive oil and milk-/cheese-processing industries as well as slaughterhouses contains high fats, oil and grease content that are difficult to degrade and may develop hydrophobicity and clogging, thus affecting the overall efficiency of CWs (Travis et al. 2012). Therefore, the application of degreaser can be helpful in reducing high oil and grease levels. In addition, the application of FWS should be

encouraged in treating wastewater with elevated levels of oil and grease as FWS has additional benefits of low construction cost and less possibility of clogging.

4. Effluents discharge from food industry may have a varied range of pH, both on acidic and alkaline sides. The performance of CWs in treating such acidic effluents can be enhanced by introducing substrate media with better neutralizing ability. In this regard, the use of limestone can be a better choice for the treatment of acidic industrial effluent from winery- and coffee-processing industries. Besides, acidic pH of influent can be adjusted by diluting organic matter through effluent recirculation.
5. Availability of land can be challenging in the treatment of huge streams of effluents generated from various industries. However, if less volume of industrial effluent is to be treated, HSSF can be an appropriate choice with better removal efficiency of contaminants.

Conclusion

In summary, CWs have been regarded as an effective and sustainable approach for domestic and industrial treatment of wastewater. In this review, we summarized classifications and various designs of CWs to obtain enhanced treatment efficiencies in industrial wastewater, particularly for food-related industries. Nevertheless, it is still unclear from the scarce data at the present to draw a conclusion, what are the key driving factors to achieve convincing demonstrations for the performance and effectiveness of constructed wetlands in these applications? Therefore, detailed investigations are required to provide convincing evidences to support the performance efficiencies in larger laboratory-scale or pilot-scale constructed wetlands. At the end, some of the challenges in obtaining high treatment efficiencies with possible solutions are highlighted.

Acknowledgement SS acknowledges financial support from the University of New South Wales, Australia.

Compliance with ethical standards

Conflict of interest All the authors declare no conflict of interest.

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