Modern Applied Science; Vol. 8, No. 4; 2014
ISSN 1913-1844 E-ISSN 1913-1852
Published by Canadian Center of Science and Education

Choosing Aquatic Plant Species for High Wastewater Treatment Efficiency through Small Wetland

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Received: May 21, 2014 Accepted: May 29, 2014 Online Published: June 25, 2014

doi:10.5539/mas.v8n4p187 URL: http://dx.doi.org/10.5539/mas.v8n4p187

Abstract

The research was aimed to choose the most appropriate aquatic plant in high capacity as grown in small wetland for community wastewater treatment, they were *Typha angustifolia* Linn., *Cyperus corymbosus* Rottb., and *Canna indica* Linn. The small wetland, sometimes called vertical flow constructed wetland (VFCW), has been designated on 100-m long, 5-m wide and 0.75-m deep in size in which four-hole pipes were laid down at the bottom for releasing some treated wastewater as effluent through the outlet to the storage reservoir. There must be paved the gravel on the bottom up to the level of 5-cm height and overtopping with sand about 15 cm that be followed by 30-cm mixed soil (soil: sand equivalent to 3:1). All selected aquatic plant species were planted in small wetland before flowing community wastewater until soil at saturated level for first week and about 30 cm during second week up to the maximum age of plants. The choosing aquatic plant species were only depended on the high efficiency of wastewater treatment. The most probable aquatic plant was selected on *Typha* as the first priority for high wastewater treatment efficiency, *Canna* the second, and more or less efficiency for the others. Fortunately, Typha has been grown well in everywhere, particularly flat wetland in central, west, east and down north of Thailand.

Keywords: aquatic plant, wastewater, small wetland

1. Introduction

Thailand had been facing the stream pollution since 1970. H.M. the King Bhumibol has realized the worsen water pollution of the country and studied the possibility on how to recover with nature-by-nature process for longer period of time before starting-up. The King's Royally Initiated Laem Phak Research and Development Project (The Royal LERD Project) has been established in the year of 1990 at Laem Phak Bia Sub-District, Ban Laem District, Phetchaburi Province, the central of Thailand. The nature-by-nature process which is extremely necessary for bacterial organic digestion processes in the tropical latitudes like Thailand as pertained to solar radiation, promising plant species, ecological niche of microorganism for organic digestion processes and plenty of organic matters as pointed out by Metcalf and Eddy (1979); Ye et al. (2001); Yang et al. (2008); Keddy (2010); Penha-Lopes et al. (2012). Actually, wetland is occurred between the terrestrial and aquatic systems in order to absorb the toxic contaminants by humus, organic matters and soils before draining away to stream or river.

Constructed wetland are becoming popular worldwide for removing contaminants from wastewater that are low-cost, easy to operate, and require less maintenance than other wastewater treatment technologies. Constructed wetland have appropriate to treat contaminants from wastewater in developing countries. Aquatic plants are main component of a constructed wetland system. They play important roles in degrading and removing nutrients and other pollutants (Cui et al., 2010). Aquatic plant has eventually to remove contaminants from wastewater and soils as growing units through root system under the osmotic pressure during the photosynthesis processing, then the elements are translocated to accumulate in all parts of vegetative organ, but it depends on the degree of toxic chemical contaminants and aquatic plant species (Tateuyama et al., 1967; Reddy et al., 1990; Rai et al., 1994; De Souza et al., 1999; Marin and Ayele, 2003; Pulford and Watson, 2003; Xia and Ma, 2006; Gupta and Sinha, 2007; Wahla et al., 2008; Thaipichitburapa et al., 2010; Zaier et al., 2010; Chunkao et al., 2012). Many studies have demonstrated that variation in nutrient removal efficiencies are attributed to different wetland plants. The principle in selection a suitable plant species for use in constructed wetland system depends on the type of wetland design. However, the choice of plants is an important issue in constructed wetland for wastewater treatment system. The most of constructed wetland system widely used common reed (*Phragmite australis*), cattails (*Typha* spp.), bulrushes (*Scipus* spp.) and reed canarygrass (*Phalaris arundinacea*) for domestic and industrial wastewater treatment system (Calheiros et al., 2007). Ornamental plants like *Canna* and *Heliconia* are used in the small wetlands to increase their aesthetic in tropical area like as Thailand. Both species has been grown well in the wetland system as well as *Canna* has high growth rate compared to *Heliconia* (Konnerup et al., 2009). In the other hands, *Typha* spp. and *Cyperus* spp. are common used in constructed wetland system in Thailand due to they are generally occurred in every parts of Thailand. *Typha* is a wetland plant with a very high water demand and limited capacity to close stomata and hence reduce water loss by transpiration. Meanwhile, *Cyperus* is formed not only in wetlands, but also on drier sites which indicates that this species has higher capacity to tolerate water stress compared to *Typha* (Kantawanichkul et al., 2009). The present study aimed to (1) investigate the tolerance of plants in small constructed wetland system for domestic wastewater treatment, (2) determine the effect to water quality of domestic wastewater treatment among plant species, and (3) determine the effect of number of rhizobacterium to treatment efficiency among plant species.

2. Method

2.1 Construction of Experimental Units

The study site is located at Laem Phak Bia sub-district, Ban Laem district, Phetchaburi Province, Thailand. The constructed wetlands have to make to layout on the soil surface, then the volumes of soils from 100x5x1-cu.m.plot sizes will be excavated with care for bed slope of 1:1,000 together with 45-degree of inclining 4 sides to protect landslide. Consequently, the plot-bed constructed wetlands must be compacted until very less seepage before laying four hole-making PVC pipes for releasing treated wastewater through the pipe-outlet at the bottom of plot bed to public water sources. The second step is focused on to pave the plot bed by gravel with size of 1.0 to 3.0 cm. in diameter about 1.0 cm. height above the hole-making PVC pipes, then topping up by medium to cause sand at about 3 to 5 cm. height above gravel surface, and finally topping up over sand surface by mixed soils (paddy soil: sand = 3:1, by weight) until at the level 0.5 of plot depth (1-m depth) (see in Figure 1)

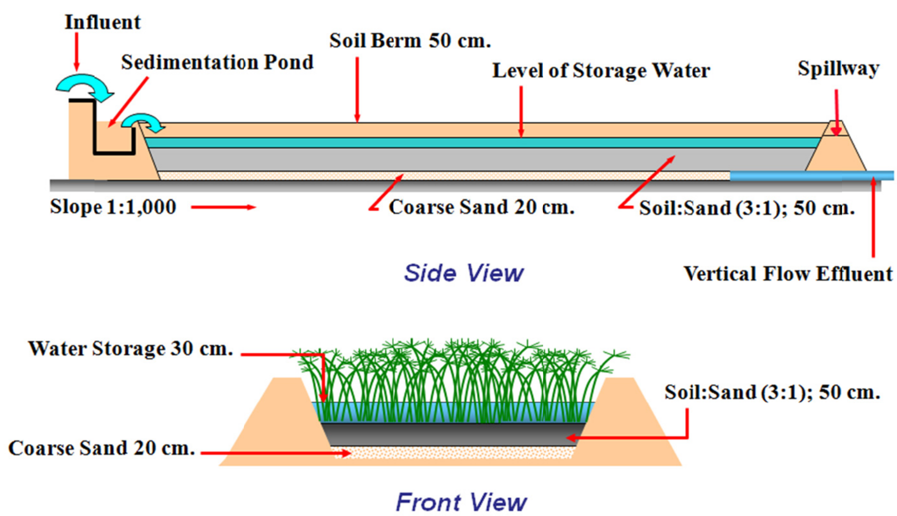


Figure 1. Plan view of constructed wetland experimental units in The Royal LERD Project

2.2 Growing Aquatic Plants

After finished the preparation of constructed wetlands, drained the natural water quality until soils being saturated would be necessary for soils, sand and gravel to adjust themselves for a few days. After that the selected aquatic plant species, *Typha angustifolia* Linn., *Cyperus corymbosus* Rottb., and *Canna indica* Linn., had to grow with 35-cm. spacing for 3 replications of each species. After 2 weeks, drained community wastewater into the plots and storage wastewater at the level 30 cm. Measured height of each species every 7 days until flowering stage of plants.

However, those aquatic plants will be clear cut off after its growth rate equivalent to zero because of very less efficiency of wastewater treatment.

2.3 Water Quality Analysis

The basic concept of analyzing water quality has to take from raw wastewater inputs and outputs. In general, the wastewater quality indicators are comprised of the followings: pH, total suspended solid (TSS), biochemical oxygen demand (BOD), total nitrogen (TN) and total phosphorus (TP). The analyzed methods of all indicators as mention above have been formulated by Metcalf and Eddy (1979); Hammer (1989); Grofse and Bauch (1991); APHA (1992); Marin and Ayele (2003); Maine et al. (2006); Hasan et al. (2007); Khan et al. (2009); Keddy (2010); Penha-Lopes et al. (2012).

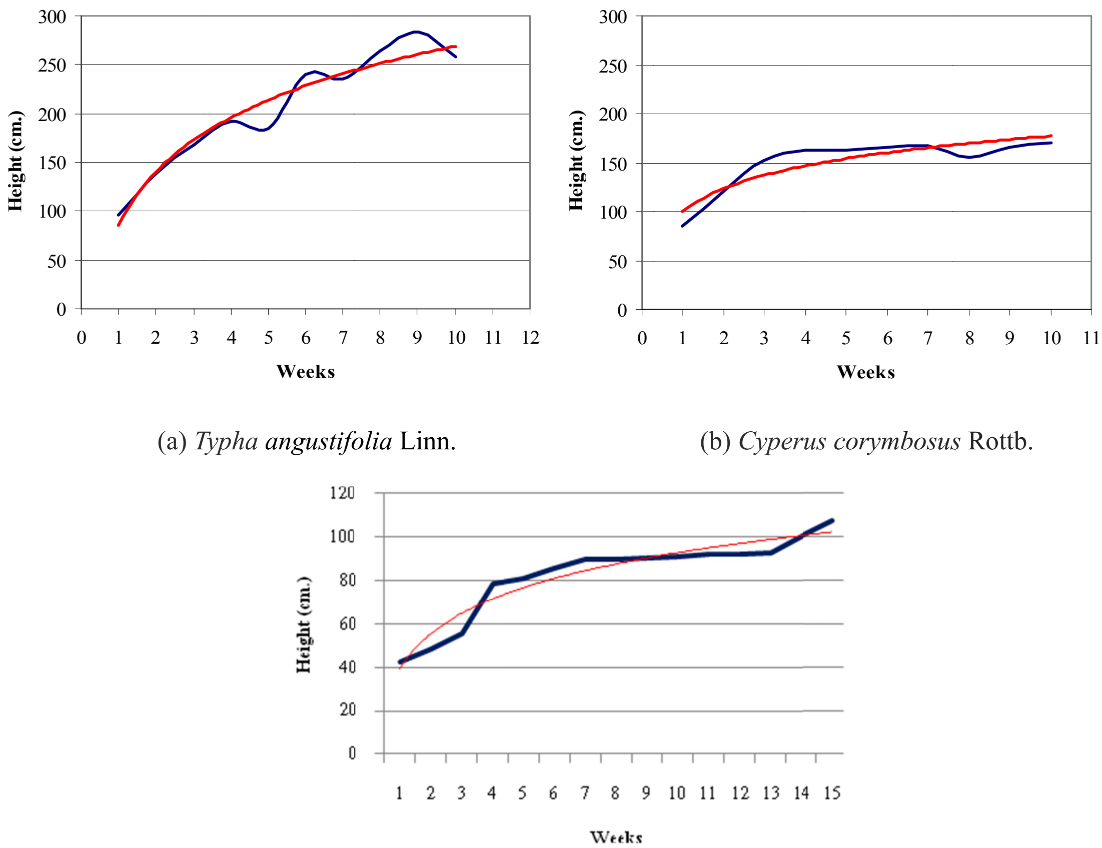
2.4 Rhizobacterium Analysis

The aquatic plant root of each species was collected in the first day of the experiments and every 15 days until the flowering stage of plants. The samples were analyzed for the number of rhizobacterium, isolate of bacteria by dilution techniques with nutrient agar (Delost, 1997; Maier et al., 2000)

3. Results and Discussion

3.1 Growth and Biomass of Aquatic Plants

Accordance with constructed wetland was proposed to conduct the community wastewater treatment under the stagnated wastewater for 5 days then releasing for 2 days before vertical flow through soil-sand-gravel layer. The experimental findings had pointed out that *Typha angustifolia* Linn, *Cyperus corymbosus* Rottb., and *Canna indica* Linn.) grew well in Phetchaburi municipal wastewater, and also the maximum effective treatment under the constructed wetland concept as shown in Figure 2. Actually, the appropriate cutting period found 90 days, 60 days, 105 days for *Typha angustifolia* Linn, *Cyperus corymbosus* Rottb., and *Canna indica* Linn., respectively.



(a) *Typha angustifolia* Linn. (b) *Cyperus corymbosus* Rottb.

(c) *Canna indica* Linn.

Figure 2. Determination of cutting period of selected aquatic plants (a) *Typha angustifolia* Linn., (b) *Cyperus corymbosus* Rottb. and (c) *Canna indica* Linn. as used for Phetchaburi municipal wastewater treatment along with 5-day stagnated and 2-day releasing wastewater on the constructed wetland

Biomass of three aquatic plants were shown in Table 1 which indicated growth production of each plant. The total biomass (stems and rhizomes) after harvesting period, showed that wet weight and dry weight of *Canna indica* Linn. was greater than *Typha angustifolia* Linn. and *Cyperus corymbosus* Rottb, respectively. Wenyin et al. (2007) and Leto et al. (2013) reported that the root growth of *Canna* with fibril roots was faster than *Typha* and *Cyperus* with rhizomatic roots due to fibril roots had higher root number than rhizomatic roots but rhizomatic roots showed a longer root lifespan than those with fibril roots. However, root biomass between the plants with rhizomatic roots and those with fibril roots were not significant. The ratio of shoot biomass to root biomass of *Canna* and *Typha* were about 2.94 and 3.10, respectively, which revealed that *Canna* had belowground yield greater than aboveground but *Typha* had aboveground yield greater than belowground. In addition, *Typha* colonized a larger surface area and produced significantly higher yields of aboveground and belowground biomass than *Cyperus*. Some previous studies reported that *Typha* in constructed wetlands for peatland restoration showed high biomass production because of the peatland as a sink in the nutrient cycle may be reactivated (Wild et al., 2001) and *Canna* can grew every well in constructed wetland condition (Konnerup et al., 2009). In the other hands, *Typha* biomass was probably less than *Cyperus* in stress condition as lack of water due to *Typha* needed very high water demand and also limited capacity to close stomata and reduce water loss by transpiration, but *Cyperus* also survived in drier sites that showed a higher capacity to tolerance water stress (Kantawanichkul et al., 2009).

Table 1. Biomass of *Typha angustifolia* Linn., *Cyperus corymbosus* Rottb., and *Canna indica* Linn. in small constructed wetland system.

Plants	Wet weight (g/m^2)	Dry weight (g/m^2)
Typha angustifolia Linn.	1,380.73 ^{b}	283.4 ^{b}
Cyperus corymbosus Rottb.	503.12 ^{a}	170.20 ^{a}
Canna indica Linn.	2,827.10 ^{c}	465.50 ^{c}

3.2 Influences of Plant Species on Water Quality

After analysis of filtrated wastewater samples of those 9 main plots, the results found the averaged values as shown in Table 2. The BOD removal efficiencies of *Typha angustifolia* Linn., *Cyperus corymbosus* Rottb., and *Canna indica* Linn., were 88.47%, 82.16% , and 86.62%, respectively. The concentration of BOD were removed by *Typha* greater than *Cyperus* and *Canna*. For making clear understanding the function of the vertical flow on aquatic plant filtration plots under the concept of constructed wetland, the water quality indicators was taken an account with BOD as the representative. In principles, the organic matter has to be digested by aerobic and anaerobic processes at the top-layer wastewater and the middle-layer soil growing media during vertical flow into the bottom of constructed wetlands. The results were related to Leto et al. (2013) who reported that *Typha* had a good level of BOD removal efficiency (72.4%) and higher BOD removal efficiency than *Cyperus* (64.8%), and Abou-Elela and Hellal (2012) reported that average BOD removal efficiency were 92% for *Canna*, *Phragmites*, and *Cyperus* with vertical flow constructed wetland(VFCW). The quality of treated effluent proved that the use of VFCW as a treatment step was an efficiency technology for small community wastewater treatment. The high removal efficiency of BOD was rapidly removed by deposition and filtration, while organic compounds were degraded both aerobic and anaerobically by the heterotrophic microorganism depending on oxygen concentration in the system.

Total suspended solid (TSS) removal efficiency of *Cyperus* (58.77%) was higher than *Typha* (48.47%), and *Canna,* (47.91%), respectively, while the efficiency of total nitrogen and total phosphorus removal were not significantly different among species. Although many reports demonstrated that *Canna* was high nutrient removal efficiency due to *Canna* were high growth rate (Konnerup et al., 2009) and *Typha* were plants that were able to establish successfully for high concentration of nutrient in wastewater treatment system (Calheiros et al., 2007), but differences in the removal of nitrate and BOD among plant species were due to differences in chlorophyll fluorescence, a photosynthetic characteristics, leading to different root lengths and total root biomass. Oxygen release to rhizosphere by wetland plant was directly governed by total root biomass and significantly influences the removal of ammonia and total dissolved phosphorus and chemical oxygen demand resulted from the filtration by root system. Nutrient uptake capacity was likely related to habitat preference and influenced by the structure of roots and rhizome. However, non-species-specific significant positive correlation was found between root oxygen release, root porosity, and radial oxygen loss rates were also positively correlated with plant tolerance to domestic wastewater and removal of total nitrogen and total phosphorus, hence nutrient removal might be not significantly different among species (Zhang et al., 2009; Li et al., 2013; Mei et al., 2014). Furthermore, the chosen species of aquatic plants were more efficient for the removal of pollutants in the long term. The different of pollutant removal efficiency among aquatic plant species were more not extremely great, especially in short period. The effect of aging on main parameters involved in pollutant removal in small constructed wetland such as temperature, pH, conductivity, dissolved oxygen concentration and redox potential (Hijosa-Valsero et al., 2012; Konnerup et al., 2009).

Table 2. Water quality indicators of vertical flow constructed wetland (VFCW) as collected at the inlet and outlet of constructed wetlands for community wastewater treatment in Phetchaburi province, Thailand

Parameter	Unit	Influent	Effluent		
			Typha angustifolia Linn.	*Cyperus corymbosus* Rottb.	*Canna indica* Linn.
pH	-	6.4	6.5^{a}	6.5^{a}	7.0^{a}
TSS	mg/l	35.9	18.5^{b}	14.8^{a}	18.7^{b}
BOD	mg/l	26.9	3.1^{a}	4.8^{b}	$3.6^{a,b}$
TN	mg/l	7.1	4.2^{a}	4.6^{a}	4.5^{a}
TP	mg/l	4.2	2.6^{a}	2.1^{a}	2.8^{a}

3.3 Influences of Rhizobacterium on Wastewater Treatment Efficiency

Typha angustifolia Linn., *Cyperus corymbosus* Rottb., and *Canna indica* Linn. were determined for the number of rhizobacterium in small constructed wetland system. *Typha* was found 8.27 x 10^6 CFU/g and 1.69 x 10^7 CFU/g in the first day and 71days of the experimental periods, respectively. *Cyperus* was found 6.49 x 10^6 CFU/g and 2.82 x 10^8 CFU/g in 57 days and very less in 71 days of the experimental period, respectively. The number of rhizobacterium in *Canna* was found about 3.97 x 10^6 CFU/g in the first day, 3.18 x 10^7 CFU/g in 43 days, and 1.37x10^7 CFU/g in 71 days of the experimental period, respectively (Table 3). The number of rhizobacterium were increased by period of plant growth, the highest number of rhizobacterium at the flowering stage, and decreased in the old stage because influences of exudates substrate from plant roots which were carbon and energy sources for bacteria growth (Sylvia et al., 1998; Gupta et al., 2000; Michael et al., 2000; Walker et al., 2003; Ibekwe & Grieve, 2004). The number of rhizobacterium in each stage of plant growth was significantly different at the level of 0.05.

Table 3. The number of rhizobacterium in *Typha angustifolia* Linn., *Cyperus corymbosus* Rottb. and *Canna indica* Linn. in Constructed Wetland System for Phetchaburi Municipal Wastewater Treatment

Days	The Number of Rhizobacterium (CFU/g)		
	Typha angustifolia Linn.(TA)	*Cyperus corymbosus* Rottb.(CC)	*Canna indica* Linn.(CA)
1	8.27 x $10^{6\ c}$	6.49 x $10^{6\ b}$	3.97 x $10^{6\ a}$
15	2.24 x $10^{6\ a}$	5.70 x $10^{6\ b}$	1.80 x $10^{7\ c}$
29	8.70 x $10^{6\ a}$	2.29 x $10^{7\ b}$	2.50 x $10^{7\ b}$
43	8.97 x $10^{6\ a}$	2.57 x $10^{8\ c}$	3.18 x $10^{7\ b\ *}$
57	1.42 x $10^{7\ a}$	2.82 x $10^{8\ c\ *}$	2.10 x $10^{7\ b}$
71	1.69 x $10^{7\ b\ *}$	1.79 x $10^{7\ b}$	1.37 x $10^{7\ a}$

Note: * flowering stage.

Isolation and identification of rhizobacterium were performed 73 isolate from root of three selected plants. *Typha angustifolia* Linn. was found 3 genus such as *Bacillus* sp., *Enterobacter* sp. and *Flavobacterium* sp. The 4 genus were found in *Cyperus* which were *Bacillus* sp., *Pseudomonas* sp., *Micrococcus* sp. and *Aeromonas* sp. and in *Canna* were found 5 genus as *Bacillus* sp**.**, *Xanthomonas* sp., *Corynebacterium* sp., *Azotobacter* sp. and *Pseudomonas* sp. *Bacillus* sp were the most generally found in each species. Other bacteria species were found *Arthrobacter* sp., *Pseudomonas* sp., *Azotobacter* sp., *Xanthomonas* sp., *Micrococcus* sp., *Corynebacterium* sp. and *Acinetobacter* sp. The report of Calheiros et al. (2009) showed that *Bacillus* sp. and *Pseudomonas* sp. were found in *Typha latifolia* in constructed wetland. The number of rhizobacterium affected to the efficiency of wastewater treatment, due to organic substrates from community wastewater, were also digested by most of these bacteria which were heterotrophic bacteria. Metabolic profiles of microbial community in wetland only depended on the presence of plants but did not depended on the plant functional group level. Diversity of microbial community all were not significantly affected by the plant functional group richness level, appearing that total shift in microbial community in the constructed wetland only depended on the presence of plant species. Increasing in plant species richness microbial biomass carbon and nitrogen and utilization of amino acids but limited the utilization of amine and amides (Zhang et al., 2010; Zhang et al., 2011). Furthermore, bacteria community change related to the type of substrate different hydraulic loading and constructed wetland operation. (Gupta et al., 2000; Misko & James, 2002; Dilfuza & Gisela, 2003; Janis et al., 2003)

4. Conclusion

The three aquatic plants were selected for 9-small experimental plots which were vertical-flow constructed wetland (VFCW). There were *Typha angustifolia* Linn., *Cyperus corymbosus* Rottb., and *Canna indica* Linn. All of plants were particular formed in tropical countries like as Thailand. The findings showed that the priority for plant selection depended on high efficiency of BOD removal, growth rate, biomass, and the number of rhizobacterium, which played important role to remove contaminants from wastewater. *Typha* was the first priority selection for small wetland domestic wastewater treatment system due to higher growth rate, biomass, and efficiency of BOD removal than other species. Although, the number of rhizobacterium of *Typha* was less than *Cyperus* and *Canna*, but the previous studies showed that microbial community were not significantly affected by the plant functional group richness level, drove the shift in microorganism for utility miscellaneous compound in constructed wetland system. Furthermore, *Typha* had been grown well, common occurred in everywhere, and cutting leaves of them could be made for handicrafts. *Canna* might be considered for small wetland domestic wastewater treatment system because of its flowers may be preferred in aesthetic condition. Hence, adaptability of a species to climatic conditions in order to ensure maximum results from the aquatic plants in wastewater treatment should be considered.

Acknowledgments

We are also in debt to The Chaipattana Foundation for conducting and supporting this study. We would like to give thanks to the staff of Eco-Science Community Group (ESCG), Department Environmental Science, Faculty of Environment, Kasetsart University for facilitating the research fund, personnel, and laboratories. With appreciation, we are thankful to our colleagues of The King's Royally Initiative Laem Phak Bia Research and Development Project for their hard working from year 1990.

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