DESIGN OF WETLAND SYSTEM FOR WASTEWATER QUALITY IMPROVEMENT AT FORMOSA HA TINH STEEL COMPANY

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Received: 10 May 2018; Accepted for publication: 22 August 2018

ABSTRACT

After a marine life disaster in central Viet Nam in 2016 due to poorly treated steel industry wastewater and pipe cleaning solutions, the Formosa Steel Corporation has been improved their wastewater treatment systems. Besides, an effluent polishing and buffer pond – wetland system has to be built. The study team has run the 500 m² pilot wetland aiming to figure out optimum design parameters such as: balancing requirements of hydraulic conductivity, hydraulic headloss, filtration efficiency and plant growth. The pilot wetland was filled with different kind of lime stone, peanut gravel and sand, running with flow rate 49.5-122.4 m³/h. The pilot test results have provided appropriate design parameters for the 4.3 ha Formosa wetland: Subsurface flow constructed wetland cells CB1, CB2, CB3 placed in series, with maximum horizontal flow rate 122 m³/h, unit hydraulic headloss 22.8cm/100m, followed by free water surface flow wetland cell CB4. The main filtration media selected for wetland cells CB1, 2, 3 was lime stone with diameter 50-100 mm (60 cm depth), where supporting layers for plant vegetation were coarse sand (20cm depth) and peanut gravel of 5-10 mm diameter (10 cm depth). The full scale 10 ha pond-wetland system now is in operation, proving design configurations of the team.

Keywords: constructed wetland, filter media, headloss, hydraulic conductivity.

1. INTRODUCTION

Constructed wetland (CW) is eco-friendly technology that utilizes aquatic plants for wastewater treatment. CW is a complex ecosystem composed of filtration materials (or media), aquatic plants, and microorganisms. The degradation process of wastewater pollutants in constructed wetland is a combination of the synergistic effects of physical, chemical and biological processes, including co-precipitation, filtration, adsorption, ion exchange, complexation, plant uptake, and microbial decomposition [1].

In many cases, CW is used for treatment of wastewater from different industries, as a polishing step, for wastewater quality improvement and for emergency control before discharge of treated wastewater to the environment, thanks to high buffer capacity of the wetland cells. In
steel industry, CW is used as an advanced treatment step for removal of manganese, iron, residual organics, color, etc. [2, 3].

As an important component of constructed wetland, the main role of filtration media includes the followings: (1) provision of reaction interface for most physical, chemical and biological processes, including sedimentation, filtration, adsorption, complexation, degradation of pollutants, etc.; (2) provision of carrier media for aquatic plants to grow; (3) provision of attachment surface for microorganisms to grow on; (4) provision of good hydraulic conditions for the wastewater flow (adapted from Zhang et al., [1]).

There are many types of filtration media applied for constructed wetlands, including gravel, limestone, sand, zeolite, soil, coal ash, slag, construction waste, etc. Number of literature has described adsorption performance and hydraulic features of different types of media. However, the literature review has shown very wide range of results, making difficulty in practical selection of the media in a concrete project. Moreover, different genesis, uniformity coefficient, cleanness, etc. of local media significantly lead to different hydraulic patterns and affect the cost of the media. Balancing all criteria such as hydraulic conductivity, headloss, total footprint required, removal efficiency and favor conditions for plants to grow is a quite interesting, but challenging exercise, and, in many cases, showing big difference between theoretical information and practical features of available media. Therefore, it is worth to conduct the test with locally available media for appropriate media selection for the constructed wetland project.

After the marine environment disaster in 2016, the Formosa Ha Tinh Steel Company (FHS) has been asked by the Viet Nam Government to build the pond system with minimum hydraulic retention time 5 days as an polishing treatment step, with a buffer volume for emergency control, and bio-indication. The CW has been introduced as a final step of the pond system, receiving treated wastewater effluent from bio-chemical wastewater treatment plant, and industrial wastewater treatment plant. The following requirements were set for the wetland cells:

- To ensure adequate hydraulic conductivity for the maximum flow rate of 36,000 m$^3$/day, with limited land area;
- To have minimum hydraulic headloss to save elevation differences among pond and wetland cells in series, for saving earth works, construction period and overall costs.
- To have maximum water depth 1m (for aquatic plants growth) while hydraulic retention time is sufficient and footprint is minimum.
- To have adequate filter media for wastewater quality improvement and for retraining of algae from ponds not to be washed out to the ocean while media should not be clogged.
- Media should create friendly environment for aquatic plants, enabling development of root system and microbial community, enhancing treatment efficiency. Local media is encouraged to save construction time and cost.
- Final wetland cell should have a free water surface area for fish rising for bio-indication and water quality supervision purposes.
- Aquatic plants on CW should survive in treated steel industry wastewater under seasonal extreme environment conditions in Ky Anh, Ha Tinh (for more information of this aspect, please find relevant paper of the same group of authors in the same Issue).

The pilot CW experiments were set up to select appropriate media for determination of design parameters before design of full scale subsurface flow (SSF) wetland cells at FHS.

2. MATERIALS AND METHODS
2.1. Experiment design and used materials

The 2 pilot CW cells have been designed to work in parallel; each was filled with different filtration media. Dimension of each CW cell A and B: length × (width on top; width in bottom) × height = 31.5 × (4.5; 4) × 1.0 m. Total depth of filtration media filled in A and B cells was 1 m, equal to maximum depth for root system to develop in SSF CW [4, 5, 6]. Water feeding to CW cells is taken from pond 1 by 2 centrifuge pump by separate pipes with regulating valves. Effluent from cells is collected in well 1, from where sent to pond 2, and then passed to pond 1 for circulation. Water depth in CW cells was regulated by lifting or lowering the L-shape pipe in the outlet of wetland cells.

Figure 1 illustrates the aggregate composition of media filled in Cell A was, bottom up: 10 cm of coarse sand for protection of HDPE liner; 60 cm of lime stone of 50-100 mm diameter as a main filtration media; 10 cm of peanut gravel of 5-10 mm diameter for preventing of top sand to enter lower media layer; 20 cm of coarse sand for plants seeding. Aggregate composition of media filled in Cell B was, bottom up: 10 cm of coarse sand; 60 cm of lime stone of 40-60 mm diameter; 10 cm of peanut gravel of 5-10 mm diameter; 20 cm of coarse sand. Main filtration media with different diameters leads to different porosity, hydraulic conductivity and headloss in 2 CW cells at the same flow rate.

2.2. Measurements and calculation methods

Flow rate of water passing through CW cells was selected as same as full scale wetland. With design capacity 36,000 m$^3$/day, wetland cell width 74 m and effective depth of main filtration media 0.6 m, the flow rate was 33.8 m/h. Based on that, flow rate through pilot CE cells was regulated at a range 50-120 m$^3$/h using valves on the discharge pipe of the feeding pumps. Precise flow passing through wetland cells Q (m$^3$/h) was measured by division of accumulated volume of water V (m$^3$) in the after-cell well 1 over a certain operation time T (h): Q = V/T.

Water level and water level difference (or headloss) along CW cell length was measured by Meter tape and Total station (tachometer).

Each CW cell was operated with 3 experimental series with different flow rates, from maximum to lower, adjusted by partial closing of valve on feeding pipe to the wetland cell. Maximum flow which could be handled by the CW cell was the value where water stared to be observed on the top of the coarse sand media. This was the evidence of hydraulic overloading of
the wetland cell; headloss reached maximum value, not keeping subsurface flow of water under the top sand layer as it was required.

Headloss values varying over flow rates were compared to theoretical headloss values. Headloss through filter bed was calculated by Carmen – Kozeny formula [7]:

\[
h_L = \frac{f}{F} \frac{L \nu^2}{e^3 d g}
\]

where: 
- \( f \) : friction factor; \( f = 150^*(1-e)/N_R + 1.75 \);
- \( N_R \) = Reynolds number; \( N_R = d^*v^*\rho_w/m; \)
- \( \nu \) = kinematic viscosity (= 0.028 m²/s);
- \( \rho_w \) = Density of water (= 1000 kg/m³).
- \( m \) = absolute viscosity (= 1.518*10⁻³ N·s/m²);
- \( e \) = porosity ratio, defined by experiment (TCVN 1772 - 1987);
- \( L \) = length of filtration module (m);
- \( d \) = media grain diameter, m;
- \( v \) : filtration velocity (m/s);
- \( g \) = acceleration due to gravity (= 9.81 m/s²).

Cross section of the wetland cell was calculated with main filtration media only, avoiding peanut gravel and coarse sand layers.

### 3. RESULTS AND DISCUSSIONS

Overflow to the top coarse sand layer occurred earlier in the cell B due to higher headloss in the cell with filtration media of smaller diameter, and, consequently, less porosity, faster increasing friction and headloss values.

Table 1. Change of headloss, and unit headloss, in pilot wetland cell A at different flow rates.

| Pilot CW (A) | Time T (s) | Flow Q (m³/h) | Water depth at outlet, cm | Water depth at inlet, cm | Cross section wet, m² | Velocity v (m/h) | Velocity v (m/s) | H (cm) | H (cm/100m) |
|--------------|------------|---------------|--------------------------|--------------------------|-----------------------|------------------|--------------------|--------|-------------|
| Series 1     | 18         | 115.6         | 62.5                     | 71.2                     | 2.88                  | 40.1             | 0.011              | 8.7    | 27.62       |
|              | 21         | 99.09         | 61.6                     | 69.4                     | 2.82                  | 35.1             | 0.010              | 7.8    | 24.76       |
|              | 29         | 71.75         | 63.8                     | 69.1                     | 2.87                  | 25               | 0.007              | 5.3    | 16.83       |
|              | 34         | 61.20         | 65.7                     | 70.6                     | 2.95                  | 20.7             | 0.006              | 4.9    | 15.56       |
|              | 41         | 50.75         | 67.1                     | 70.2                     | 2.98                  | 17.1             | 0.005              | 3.1    | 9.84        |
| Series 2     | 17         | 122.40        | 70.8                     | 70.8                     | 3.08                  | 39.7             | 0.011              | 8.2    | 26.03       |
|              | 25         | 83.23         | 68.7                     | 68.7                     | 2.98                  | 27.9             | 0.008              | 6.1    | 19.37       |
|              | 28         | 74.31         | 68.6                     | 68.6                     | 2.98                  | 24.9             | 0.007              | 4.8    | 15.24       |
|              | 32         | 65.03         | 69.1                     | 69.1                     | 3.00                  | 21.7             | 0.006              | 3.1    | 9.84        |
|              | 39         | 53.35         | 65.7                     | 68.7                     | 2.91                  | 18.3             | 0.005              | 3.0    | 9.52        |
| Series 3     | 19         | 109.52        | 69.8                     | 69.8                     | 3.04                  | 36.1             | 0.010              | 8.0    | 25.40       |
|              | 22         | 94.58         | 68.5                     | 68.5                     | 2.97                  | 31.8             | 0.009              | 7.1    | 22.54       |
|              | 29         | 71.75         | 69.7                     | 69.7                     | 3.03                  | 23.7             | 0.007              | 5.0    | 15.87       |
|              | 33         | 63.05         | 70.2                     | 70.2                     | 3.05                  | 20.6             | 0.006              | 4.1    | 13.02       |
|              | 42         | 49.54         | 69.9                     | 69.9                     | 3.04                  | 16.3             | 0.005              | 2.9    | 9.21        |

Maximum flow rate for cell B with filtration media of 40-60 mm diameter was 82.7 m³/h, equal to horizontal flow filtration velocity 30.7 m/h. For cell A, water overflow occurrence was observed at flow rate 122 m³/h (Table 1).
The results in the tables shown that, significant difference in headloss values in 2 cells was observed. At cell B with smaller filtration media diameter, headloss was increasing from 6.6 cm to 16.3 cm while flow rate was increasing from 49.2 m$^3$/h to 82.7 m$^3$/h. At cell A, during increase of flow rate from 49.5 m$^3$/h to 122.4 m$^3$/h, headloss was increasing from 2.9 cm to 8.7 cm. Unit headloss of the cell A was 22.8 cm/100 m. With total length of full scale wetland cells at FHS 450 m, and maximum design flow rate 36,000 m$^3$/day, total headloss over wetland system could reach 1.01 m. This was an important value to determine construction elevation of full scale wetland cells CB1, 2, 3, 4 at FHS.

Table 2. Change of headloss, and unit headloss, in pilot wetland cell B at different flow rates.

| Pilot CW (B) | Time T (s) | Flow Q (m$^3$/h) | Water depth at outlet (cm) | Water depth at outlet (cm) | Cross section wet (m$^2$) | Velocity $v$ (m/h) | Velocity $v$ (m/s) | H (cm) | H (cm/100) |
|-------------|------------|------------------|---------------------------|---------------------------|-------------------------|-------------------|-----------------|--------|-------------|
| Series 1    | 26         | 79.48            | 55.2                      | 70.5                      | 2.687                   | 29.6              | 0.008           | 15.3   | 48.57       |
|             | 30         | 68.88            | 61.4                      | 69.2                      | 2.812                   | 24.5              | 0.007           | 7.8    | 24.76       |
|             | 35         | 59.04            | 61.1                      | 69.3                      | 2.807                   | 21.0              | 0.006           | 8.2    | 26.03       |
|             | 41         | 50.40            | 64.0                      | 70.6                      | 2.907                   | 17.3              | 0.005           | 6.6    | 20.95       |
| Series 2    | 25         | 82.66            | 54.0                      | 70.3                      | 2.654                   | 31.1              | 0.009           | 16.3   | 51.75       |
|             | 32         | 64.58            | 60.9                      | 69.0                      | 2.796                   | 23.1              | 0.006           | 8.1    | 25.71       |
|             | 36         | 57.40            | 60.4                      | 69.2                      | 2.788                   | 20.6              | 0.006           | 8.8    | 27.94       |
|             | 42         | 49.20            | 62.5                      | 70.0                      | 2.857                   | 17.2              | 0.005           | 7.5    | 23.81       |
| Series 3    | 25         | 82.66            | 55.7                      | 70.0                      | 2.689                   | 30.7              | 0.009           | 14.3   | 45.40       |
|             | 31         | 66.66            | 60.1                      | 69.2                      | 2.780                   | 24.0              | 0.007           | 9.1    | 28.89       |
|             | 36         | 57.40            | 61.2                      | 69.4                      | 2.812                   | 20.4              | 0.006           | 8.2    | 26.03       |
|             | 41         | 50.40            | 63.2                      | 70.3                      | 2.881                   | 17.5              | 0.005           | 7.1    | 22.54       |

Filtration media with diameter 40-60 mm was considered not suitable for wetland cells at FHS. Table 2 shows that water flow evidence occurred at flow rate as small as 82.7 m$^3$/h. At this flow rate, the unit headloss reached 51.8 cm/100 m. That means if this type of media would be selected for FHS wetland cells with design capacity 36,000 m$^3$/day, total headloss over 4 wetland cells could be 2.33 m. Too much headloss would lead to significant increase of elevation of frontier pond cells, increase of pump head, increase of earth works, and prolongation of construction period. Alternative solution could be decrease of flow velocity through wetland cross section. Consequence of this would be increase of media depth or wetland cell area. Besides negative effect to plants growth, as discussed in the introduction, increase of total media volume and required cell area lead to increase of project costs. Flow velocity values versus headloss, experimental and theoretical values in pilot wetland cell A and cell B are represented in Figure 2.
Figure 2. Flow velocity values versus headloss, experimental and theoretical values in pilot wetland cell A and cell B.

Measured headloss, and theoretical headloss using Carmen – Kozeny formula were different in values but at the same evolution trend. This was an evidence of formula correctness and experiment values reliability. Higher values of measure headloss were explained due to dirty filtration media, combining muddy soil, and inhomogeneity of the media filled into cells. This is an important factor to be considered in selection and filling of media into the wetland cells. Filtration media should be well sieved to maximum uniformity, and should be cleaned. In the case use of uniformed grain media size and cleanness was not possible; safety factor for headloss increase should be taken in the design. Most reliable approach is to conduct experiments on real media for determination of hydraulic conductivity, headloss, and other field parameters, as it was done at FHS project.

Due to filtration media with diameter larger than 50-100 mm had high void value and low treatment efficiency [8, 9], therefore, lime stone with diameter 50-100 mm has been selected to fill into subsurface flow constructed wetland cells CB1, CB2, CB3 at FHS. For final wetland cell CB4, free water surface wetland was selected for rising of fish as bio-indication purpose.

4. CONCLUSIONS

Filtration media plays an important role in constructed wetland. Balancing all criteria for wetland media such as hydraulic conductivity, headloss, total footprint required, removal efficiency and favor conditions for plants to grow is a challenging exercise for locally available media. Experiments have provided valuable information for selection of design parameters for media at FHS wetland: 60 cm depth media of 50-100 mm diameter run at flow rate 122 m$^3$/h had unit headloss 22.8 cm/100 m, equal to total headloss 1.01 m over total length of full scale wetland cells at FHS 450 m, and maximum design flow rate 36,000 m$^3$/day. Measured headloss, and theoretical headloss using Carmen – Kozeny formula were different in values but at the same evolution trend. This was an evidence of formula correctness and experiment values reliability. Higher values of measure headloss were explained due to dirty media, combining muddy soil, and inhomogeneity. In the case use of uniformed grain media size and cleanness was not possible, safety factor for headloss increase should be taken in the design. Most reliable
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