Assessment of Clogging in Constructed Wetlands

Guilherme Manuel Pereira Correia
guilherme.correia@tecnico.ulisboa.pt

Instituto Superior Técnico, Lisboa, Portugal

June 2016

Abstract

The main goal of this thesis is the assessment of the clogging degree in the horizontal subsurface flow constructed wetland of Martinlongo and Barrada WWTP, included in Algarve Multi-Municipal Sanitation System

Despite of constructed wetland treatment processes being natural and constructed wetlands easy to operate, clogging phenomena can be quite complex and challenging in a way that it is necessary to understand what is going on in the whole system. In order to do so, a deep search of relationships between the wetland components and the interactions of these with the operation mode was needed, as well as an identification of the influence factors and impact of each one.

The main symptom of clogging is water insurgence, which leads often to pond formation and surface runoff. This are undesired consequences due to the risk associated with the wastewater exposure at the surface. Ultimately, clogging problem can be so severe that deep intervention is needed and so it is definitely an issue that shortens the life span of these equipment's.

The assessment of the two constructed wetlands clogging degree used saturated hydraulic conductivity measurements obtained with the Falling Head Method. The investigation reported in this document reveals that Martinlongo WWTP constructed wetland is really clogged in the majority of its area, with the exception of the inlet zone (recently rehabilitated), and that Barrada WWTP constructed wetlands has already some preoccupying dispersed values meaning the existence of preferential flow paths and showing where the first symptoms of clogging will occur.

Keywords: clogging, hydraulic conductivity, constructed wetlands, wastewater.

1 Introduction

Constructed wetlands are designed to promote the occurrence of natural processes that purify the wastewater, as it happens in some natural wetlands. Kadlec et al. (2000) describe wetlands as a complex combination of water, substrate, plants (vascular and algae), organic litter, invertebrates and a mix of microorganisms from which bacteria are the most important.

The use of subsurface flow constructed wetlands (SSF CWs) for wastewater treatment has been very important in Portugal to supply this service to populations under 2000 inhabitants. Considering geographically dispersed populations, this type of system has some advantages over conventional systems hence the maintenance and operation costs are low, staff do not require specific training and mostly no electrical power or electrical equipment is needed.

Horizontal subsurface flow constructed wetlands (HSSF CWs) are beds filled with soil or gravel, vegetated at the top by macrophytes, plants adapted to wetlands (Figure 1), that suffer progressive clogging as consequence of its operation. The clogging phenomena may compromise the efficiency and safety of the treatment. Moreover, clogged beds are susceptible to pond formation and surface runoff, which endanger public health and the environment.

The main causes of clogging are solids accumulation within bed media pores, inadequate design, excessive loading of organic matter and suspended solids. The solids accumulation might result from biofilm growth, vegetal debris, roots and rhizomes development, wastewater solids entrapment, and chemical precipitation (A. Pedescoll et al., 2009).

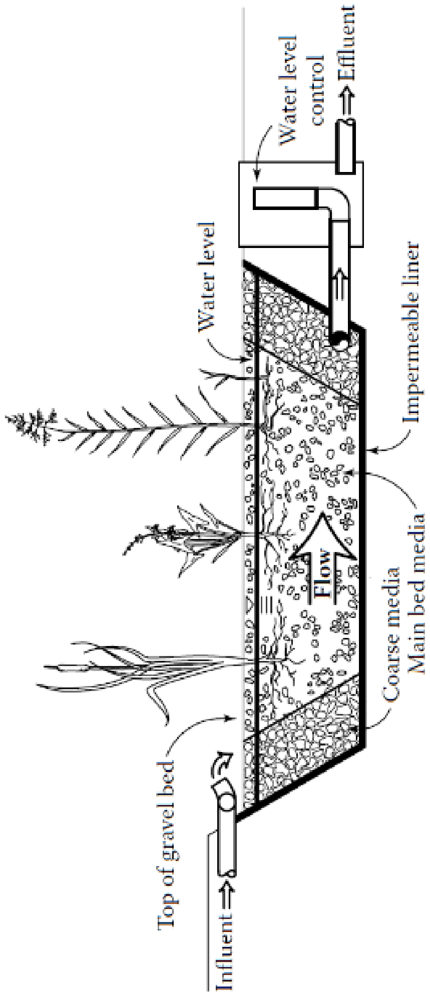

Figure 1 - HSSF wetland schematic (from Kadlec & Wallace, 2009)

The field work presented in this document resulted from the will of Águas do Algarve, S.A, which detected and reported water insurgencies in one constructed wetland of Martinlongo WWTP. This HSSF CW had been subjected to an intervention in the inlet and outlet areas, which are more prone to clog. In order to better understand this phenomena, measurements of the saturated hydraulic conductivity were taken according to the Falling Head Method to assess the clogging degree. The same procedure was realized in the HSSF CW of Barrada WWTP, which didn't had symptoms of clogging, in order to validate the results and to be used as a comparison.

2 Horizontal Subsurface Flow Constructed Wetlands

Horizontal Subsurface Flow Constructed Wetlands typically are designed to treat primary effluent prior to either soil dispersal or surface water discharge. The wastewater is intended to stay below the surface of the media and to flow through it passing by rhizomes and roots until the outlet. Because water is not exposed during the treatment process, the risk associated with human or wildlife exposure to pathogenic organisms is minimized. If properly operated and designed, HSSF wetlands don't provide habitat for mosquitoes (Kadlec & Wallace, 2009).

This concept of treating wastewaters with horizontal subsurface flow constructed wetlands started during the 70's in Germany. The first operational HSSF CW was built in 1974 in Othfresen, Germany (Kadlec et al., 2000).

Primarily, soil was used as bed media and therefore those systems were prone to clog and to have surface runoff. In order to mitigate this events, HSSF CW's begin to have gravel porous media instead of soil (Kadlec et al., 2000). Nevertheless, clogging is the major operational problem this technology faces since it exists. In extreme situations, surface runoff due to clogging is such that the system starts to work as a surface flow constructed wetland (Kadlec & Wallace, 2009)

Smaller bed media have a higher specific area and therefore the biofilm has more surface for its establishment. Also, the smaller volume of the pores leads to a high efficiency in solids entrapment. This characteristics are good for the treatment efficiency, but they compromise the life time of the system because they accelerate clogging. The use of coarser bed media is recommended due to the bigger pores, which don't get blocked so rapidly with the accumulation of biosolids. The gravel should be made of an inert material and the size choice must consider the constructed wetland design and the wastewater characteristics (Kadlec & Wallace, 2009).

The total suspended solids (TSS) and biochemical oxygen demand (BOD removal occurs by flocculation, sedimentation and filtration processes. The high efficiency treatment of HSSF CW for this two parameters is due to the low speed flow and to the wide contact surface area that wastewater flows by (USEPA, 2000).

Usually HSSF CWs perform secondary treatment to domestic wastewater. In Europe most of them are designed for 500 p.e. Nevertheless, this systems versatility allows many other applications, namely on-site applications such as treatment facilities of hospitals, farms, schools and other similar infrastructures. This is only possible due to the system efficiency, simplicity and economic viability (Kadlec et al., 2000).

3 Clogging in Horizontal Subsurface Flow Constructed Wetlands

HSSF CW clogging is the process of bed media pores occlusion. The clogging progression speed depends on the design and operation context of the constructed wetland (Knowles et al., 2011).

In other words, clogging is the bed media porosity loss by solids accumulation. Accumulated solids might be organic or inorganic, and they may origin from the wastewater or from biological activity.

Clogging is a severe operational issue that may lead to the increase of disease dissemination as well as diminish the treatment efficiency. Commonly, rehabilitation measures are only taken when visible symptoms show up, such as pond formation or surface run off.

The clogging process depends on a wide variety of factors and on the dynamic relationships between these factors among themselves. Due to that complexity, clogging phenomena is not currently known in detail. Nevertheless, during this research, many clogging related factors were identified, and hereby organized in three categories, Table 1. The factors of the first two categories (influent characteristics and system design), where the chance of intervening is bigger, have a strong influence over the third category (bed activity) factors.

Table 1 – Clogging related factors by categories

Influent Characteristics	System Design	Bed activity
Pretreatment	Shape	Rhizosphere
BOD_5 concentration	Sizing	Biofilm
TSS concentration	Operation mode	Chemical processes
Flow	Distribution System	Accumulated matter composition
	Collection system	
	Pipes	
	Bed media	
	Macrophytes	

Each factor might be related with more than one clogging mechanism and have influence in different ways. The main clogging mechanisms are suspended solids retention, biofilm growth, excessive load of organic matter and uneven influent distribution.

Suspended solids entrapment occurs mainly in the inlet zone where the wastewater has a higher content of suspended matter. Due to the low speed of the flow, suspended solids settle at the inlet. The more the pores volume diminish, the lower the hydraulic conductivity will be.

The biofilm growth is prevalent in the inlet zone because of the high content of organics present in the influent wastewater (Ragusa et al., 2004; García et al., 2007; Tietz et al., 2007). The development of biofilm is dependent on the rate of particles and soluble organics that entry in the bed, therefore it is affected by the nature of the wastewater to be treated. The porosity loss resultant from biological activity contributes to an important decrease in hydraulic conductivity at the inlet.

The influent excessive organic matter content exacerbates the microbial biomass growth. Usually, the organic load is related to the amount of accumulated solids(A. Pedescoll et al., 2013).

According to Rosseau et al. (2005) and Griffin et al. (2008) poorly maintained distribution systems lead to an uneven distribution. Therefore, bed media clogging may be uneven likewise(P. Knowles et al., 2011). If the wastewater flows only through the same holes of the distribution pipes, it is likely that surface plugging will happen. In such cases maintenance and improvement of the distribution system may prove beneficial (USEPA, 2000).

The HSSF CW clogging produces a chain of adverse effects since the accumulated solids within the bed media favors short-cuts and hence the hydraulic conductivity decrease as well as the pores' volume. As a consequence, water insurgences and other undesired events may happen, leading to a reduction of the treatment efficiency, a negative impact in the environment, and an increase of the expenses with the maintenance (Turon et al., 2009).

The main clogging preventive measures consist of an efficient pretreatment, an adequate distribution system, as well as the choice of an appropriate bed media and guaranteeing the accomplishment of maintenance procedures.

The existence and the appropriate operation of the pretreatment is important to avoid the entrance of coarse solids and to decrease the influent concentrations of BOD_5 and TSS. This way, the coarse solids entrapment and consequent bed clogging is prevented (Pedescoll et al., 2011).

The conventional clogging remediation measures are the improvement and/or distribution pipes cleaning, the bed media washing or replacement, accumulated organic matter oxidation by hydrogen peroxide, and the recirculation of the effluent in order to decrease the influent organic load. An alternative to the bed media washing is the application of worms, since they graze the accumulated solids and also aerate the bed media while moving.

4 Clogging assessment in Horizontal Subsurface Flow Constructed Wetlands of Martinlongo and Barrada WWTP

Both Martinlongo and Barrada WWTP provide wastewater secondary treatment to the 431 inhabitants of Martinlongo and the 133 inhabitants of Barrada. In the two WTTP, pretreatment and secondary treatment devices are the same, a grit removal equipment and a HSSF respectively. Only the primary treatment uses different equipment's, being the Martinlongo WTTP equipped with an Imhoff tank and Barrada with a septic tank. Considering all the equipment's of both WWTP, only the Martinlongo Imhoff tank shows in analysis data signs of decreased efficiency of TSS removal.

The HSSF CWs consists of three main layers. The first one is a 10 cm soil layer that covers the 40 cm second layer, of 3mm gravel in Martinlongo and of 6 to 12 mm in Barrada. The bottom layer is composed by 50 mm gravel to facilitate the drainage. The height of this layer increases towards the exit according to the bottom slope. Both meds are colonized with *Phragmites australis*.

The elected method to assess the clogging degree was the Falling Head Method which measures the saturated hydraulic conductivity by applying a vertical hydraulic load in a tube inserted in the bed media. The measurements don't results in a very accurate value of hydraulic conductivity since the value is influenced by the method, the flow, the system dimensions, the sampling technique, and the physic and hydrological characteristics of the bed media (Knowles et al., 2010).

For each hydraulic load, the pressure variation that the water column exerted in the probe was registered in function of the time. Usually, the curve shape is a negative exponential that represent the decrease of water column height in function of time. The curve obtained is liked to hydraulic conductivity through Lefranc's formula:

$$K = \frac{d^2 ln\left(\frac{2L}{d}\right)}{8Lt}\, ln\left(\frac{h_1}{h_2}\right)$$

where *K* is saturated hydraulic conductivity, in m/s; *h1* is the water height at time zero, in m; *h2* is the water height at time *t*, in m; *d* is the tube diameter, in m; *L* is the length of the submerged part of the tube (perforated zone), in m; *t* is time, in s.

The values of hydraulic conductivity were obtained with statistical analysis between the obtained curved and modeled curves with different *K*. The hydraulic conductivity value of each test is the one correspondent is the one that the modelled curve fits better the experimental curve:

$$\sum_{t=0}^{t=x} \left(h_2 - f(h_1)\right)^2 \rightarrow 0$$

where *x* is the duration of each test, in s, and *f(h2)* is the modelled data, in m.

In order to assess clogging degree, the hydraulic conductivity measurement were taken in three transects in both beds, as shown in Figure 2 and Figure 3.

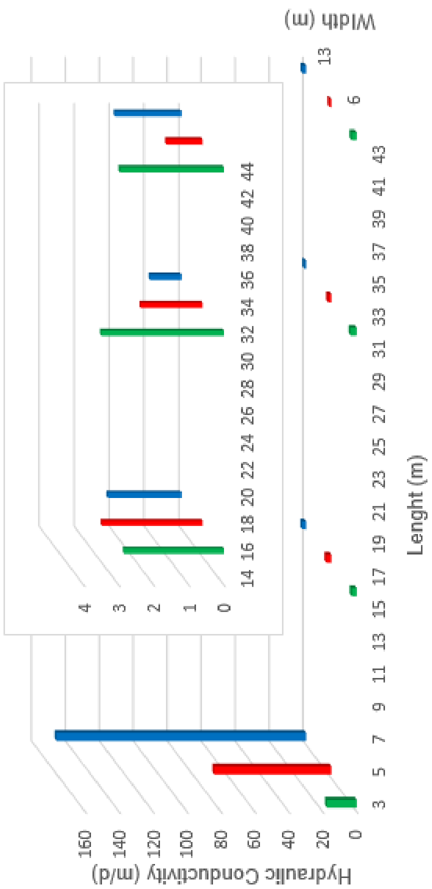

Figure 2 – Mean values of hydraulic conductivity measurements in the three transects of Martinlongo HSSF CW. In the top right corner is the same graphic scaled from 0 to 4 m/d to show the differences among the lower values.

In general, Martinlongo HSSF CW has very low hydraulic conductivity values, being the most of them below 4 m/d. The higher values correspond to the inlet zone. In this case the values vary from 0,9 m/d to 146,9 m/d.

The low hydraulic conductivity is probably due to the small size of the bed media and to the malfunctioning Imhoff tank. These two factors combined increase the chances of heavy clogging.

Regarding the primary treatment, it is recommended to improve the Imhoff tank performance by increasing the purge frequency.

The inlet zone requires special attention as during the investigation days superficial mud and vegetal debris were present. The maintenance of this area is very important to prevent macrophytes invasion as it happened in the past. The cleaning of superficial accumulated solids is also important to keep the bed free from mosquitoes and rodents. Moreover, it is recommended to rake the superficial layer to promote the aeration. This considerations are also suitable to the outlet zone.

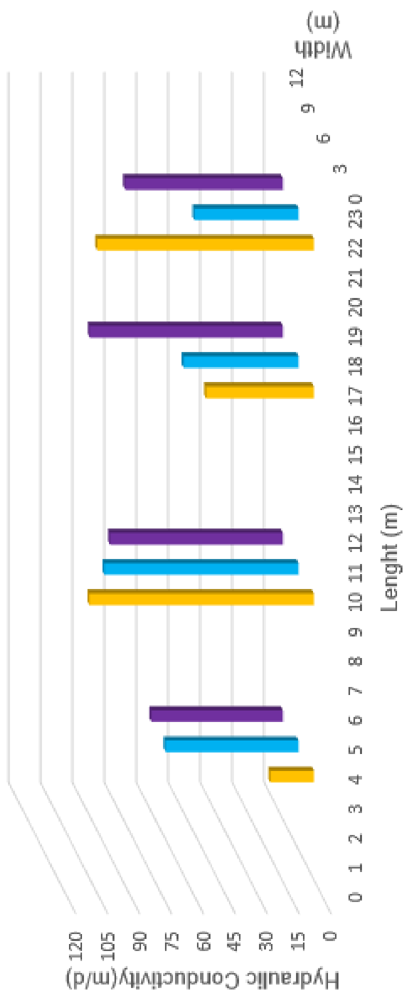

Figure 3 – Mean values of hydraulic conductivity measurements in the three transects of Barrada HSSF CW.

Concerning the Barrada HSSF CW hydraulic conductivity values and the noticeable heterogeneous pattern, it is very likely that short-cuts are being formed. Despite the absence of visible clogging symptoms, the lower values of hydraulic conductivity belong to the inlet and outlet areas, the areas more prone to clog. Therefore maintenance activities in those areas should not be neglected.

5 Conclusions

The subsurface flow constructed wetlands are an excellent solution to provide sanitation systems for smaller populations to whom the connections with centralized systems are not viable. Nonetheless, the clogging phenomena threatens treatment efficiency, increases the risk of wastewater exposure to people or animals, and also shortens the system life time.

There have been identified clogging preventive and rehabilitative measures to significantly increase beds' life span. These would be relevant to avoid surface runoff and to accomplish treatment goals.

Clogging degree assessment of both HSSF CW through saturated hydraulic conductivity measurements allow us to conclude that Martinlongo's WWTP is heavily clogged apart from the initial area. It allow us infer that Barrada's WWTP has a heterogeneous pattern in what respects to hydraulic conductivity distribution, pointing towards the existence of preferential flow paths.

Martinlongo's WWTP should, therefore, aim to correct Imhoff's tank efficiency or implement a complementary solution as sedimentation basin previous to primary effluent distribution. Additionally, intermediate layer bed media replacement with a larger bed media may prove of greater potential to increase bed hydraulic conductivity as well as to avoid clogging effects.

References

Kadlec, R.; Knight, R.; Vymazal, J.; Brix, H.; Cooper, P. e Harbel, R. (2000). *Constructed Wetlands for Pollution Control - Processes, Performance, Design and Operation.* IWA Publishing, London.

Kadlec, R. H., & Wallace, S. (2009). *Treatment Wetlands*. http://doi.org/10.1201/9781420012514

Knowles, P., Dotro, G., Nivala, J., & García, J. (2011). Clogging in subsurface-flow treatment wetlands: Occurrence and contributing factors. *Ecological Engineering*, *37*(2), 99–112. http://doi.org/10.1016/j.ecoleng.2010.08.005

Knowles, P. R., Griffin, P., & Davies, P. A. (2010). Complementary methods to investigate the development of clogging within a horizontal sub-surface flow tertiary treatment wetland. *Water Research*, *44*(1), 320–30. http://doi.org/10.1016/j.watres.2009.09.028

Pedescoll, A., Corzo, A., Álvarez, E., García, J., & Puigagut, J. (2011). The effect of primary treatment and flow regime on clogging development in horizontal subsurface flow constructed wetlands: An experimental evaluation. *Water Research*, *45*(12), 3579–3589. http://doi.org/10.1016/j.watres.2011.03.049

Pedescoll, A., Sidrach-Cardona, R., Sánchez, J. C., Carretero, J., Garfi, M., & Bécares, E. (2013). Design configurations affecting flow pattern and solids accumulation in horizontal free water and subsurface flow constructed wetlands. *Water Research*, *47*(3), 1448–1458. http://doi.org/10.1016/j.watres.2012.12.010

Pedescoll, A., Uggetti, E., Llorens, E., Granés, F., García, D., & García, J. (2009). Practical method based on saturated hydraulic conductivity used to assess clogging in subsurface flow constructed wetlands. *Ecological Engineering*, *35*(8), 1216–1224.

Turon, C., Comas, J., & Poch, M. (2009). Constructed wetland clogging: A proposal for the integration and reuse of existing knowledge. *Ecological Engineering*, *35*(12), 1710–1718. http://doi.org/10.1016/j.ecoleng.2009.06.012

US Environmental Protection Agency. (2000). *Constructed Wetlands Treatment of Municipal Wastewaters*.