Article

Innovative effluent capture and evacuation device patented that improves behavior of horizontal subsurface flow wetlands

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Abstract: Currently, several researchers are working to improve the artificial wetlands performance and make them a competitive alternative to conventional treatment mechanisms. In the same vein, this paper analyzes the performance of subsurface flow wetlands removal by COD concentration, suggesting two different hydrodynamic solutions. Firstly, we worked on wetlands at pilot scale and in a real-scale wetland. This subsurface flow wetlands behaviour (HFSS) and its elimination results of organic matter were evaluated in function on the configuration and structure of the capture and evacuation effluent device. The traditional and innovative capture and evacuation effluent device were compared. In this experience, this innovative device designed for the collection and effluent evacuation was applied for the first time, what is in a process of patenting and constitutes an unprecedented improvement in wastewater treatment through HFSS. This innovative tool for capture and evacuation of the effluent, was designed and built to cover the entire width and height of the wetland, its incidence is in the entire cross-sectional area of the flow. The results show that the incorporation of the innovative device improves the wetland hydrodynamic condition, increasing the biodegradation yields of the carbonaceous organic matter. The HFSS behaviour was evaluated using both effluent capture and exit devices, comparing the respective removal efficiencies of organic matter and nitrogen. We analyzed the HFSS behaviour using both configurations (devices), evaluated and determined the incidence in the elimination efficiency of COD and nitrogen in both devices. Using the innovative effluent outlet device, the COD removal performance exceeds that of the conventional device by 10%. The improvement of the yield will allow the reduction of wetland surfaces for the same treatment horizon or the same pollutant load.

Keywords: Artificial Wetlands, Horizontal Wetland, Subsurface Flow

1. Introduction.

The aim of this work is to evaluate the impact on the HFSS behavior by incorporating an innovative device in the capture and exit of the effluents from horizontal subsurface wetlands. Said device was installed in a pilot-scale wetland and in a real wetland and its organic ammonium elimination yields were evaluated. As a consequence, there was an, increase in the efficiency of organic matter removal from domestic wastewater, at a low cost of investment, operation and maintenance, and complying with the water quality standards required by the current regulations of the country.

It is considered that the water is contaminated, when their chemical, physical and biological characteristics or composition has been altered, thusthat it loses their potability for daily consumption or for its use in domestic, industrial or agricultural activities, which generates wastewater [1]. Wastewater can be of domestic, industrial, agricultural, and rainwater origin [2].

Wastewater generated in human activities has a high load of organic material. Certainly, it possess toxic substances and inorganic matter in smaller magnitude and as a consequence the sum of both components pollute water sources and undermine the sustainability of nature and humanity. Therefore, treatment systems that include physical, chemical and biological processes are implemented. The objective is to reduce the load of pollutants from wastewater and, ideally, to recover them, recycle and reuse them before pouring it into bodies of surface water [3].

Wastewater contains useful products, such as water, organic matter, some salts and also some harmful products. The latter must be separated from useful products that could benefit the population [4]. Efficient treatment systems have been developed for the removal of pollutants, which are also viable in economic, technical and social terms, such as the Artificial Wetlands of SubSuperficial Flow (HFSS), [5]. Moreover, artificial wetlands have proven to be efficient in eliminating excessive nutrient loads, erasing 60% -80% of total nitrogen for input loads between 3 and 36 (kg N / ha · d). [6]. Furthermore, the levels of removal of contaminants can be increased by modifying the design of the input geometry of the wetland or by modifying the form of distribution of the flow and its direction within the system [7].

Artificial wetlands efficiently reduce the Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and Nitrogen (N) (yields over 80%), achieving adequate treatment levels with low energy consumption and simple maintenance [8]. The biodegradation rate of organic matter is lower, which is why 20 to 50 times more land area is required in the artificial wetland system than in conventional systems [9].

In artificial wetlands, soluble organic compounds are biodegraded by aerobic processes where oxygen is supplied directly from the atmosphere by diffusion and mainly through the process of photosynthesis, into the water column [10]. Microorganisms that are attached to the support medium in subsurface flow systems are those that biodegrade the soluble organic compounds [11], the degradation rate being 10 times faster than that of the anaerobic processes [12]. On the other hand, aerobic processes are the main mechanism to reduce soluble BOD, and the elimination of particulate BOD occurs rapidly by sedimentation and particle filtration in the spaces between gravel and roots [13].

The structural factors that affect the removal of organic matter are related to the depth of the device, which in turn is conditioned by the root depth, depending directly on the species and type of plant used, emerging plants such as cattails and reeds, the depth It will be less than 60 cm. The vegetation provides surfaces for the formation of bacterial films, facilitating the filtration and adsorption of pollutants from wastewater and controls the growth of algae by limiting the penetration of sunlight [8]. The most commonly used plant species are emerging macrophytes typical of humid areas such as reeds (Phragmites sp.), Bulrush (Typha sp.) Or reeds (Scirpus sp.) [14].

These plants present great adaptation in saturated environments, fast growth, are strong and resistant to climatic changes, and are not a source of food for animals [15]. One of the criteria for the selection of plants is the adaptation of these to the environmental conditions where a wetland is planned to be built, for this reason species should be used, preferably, typical of the local flora [14].

Hence, in these wetlands, the feeding is continuous, the waters cross horizontally a filtering substrate of gravel, the one that follows its course by the effect of gravity, given the gentle slope of the bottom towards the exit of the wetland, allowing the contact between the residual water, the substrate and the roots of the plants and the hydraulic retention time is 2 to 5 days. An impermeable barrier must be installed to confine the residual water and avoid contamination of the groundwater, which must be resistant, smooth and protected against puncturing by sharp gravel [16]. The most used waterproofing material is high density polyethylene. It is recommended to use gravel of 20 to 30 mm, if gravel with larger diameters is used, the speed of the water is increased, on the contrary, gravels of too small diameter, reduce the speed causing possible floods and preferential flows [17].

The ratio (length: width) must be greater than (3: 1) to approximate a piston-type flow, which is directly related to the slope used at the bottom of the wetland bed, which determines the velocity of the flow [18]. The most used slope is from 0.5 to 1%. Studies results consider that 10% of the bed depth at its entrance (Hi) can be used, due to the length of the wetland (L) [19]. The Basic Model of Organic Matter Removal is applied in piston flow reactors for HFSH [20]. This model has been validated [21] and relates the removal capacity of contaminants and the hydraulic residence time.

$$dCa/dt = K_T * C$$

$$C_e/C_0 = exp(-K_T * TRH) \qquad y \quad TRH = V/Q = (As*h*n)/Q$$

$$A_S = Q * \frac{ln\left(\frac{C_0}{C_e}\right)}{K_T \cdot y \cdot n} \qquad Eq. 1$$

Table I Parameters of design

Co	Concentration of BOD in influent, mg / l
Ce	Concentration of BOD in effluent, mg / l
HRT	Hydraulic residence time, d
As	Surface area of the wetland, m2
n	Porosity of the wetland
y	Depth of water in the wetland, m
Q	Average flow rate of the wetland, m3 / d
$k_t, d-1$	Constant dependent on temperature, $= K_{20} * 1,06^{T-20}$

K_{20} = 1.104 d-1 Constant kinetics of organic matter removal at 20°C.

2. Materials and Methods

In the sub-surface flow wetland of Recreational Center Ainahue, it is located in Hualqui, province of Concepcion, whose coordinates are U.T.M. 686393.79 m E; 5905081.35 m S (Figure 1). These pilot wetlands are located in dependencies of the University of Bío Bío, Campus Concepción, in the city of Concepción. The dimensions of these wetlands can be seen in Table II.

Figure N°1. Wetlands of horizontal subsurface flow.

TABLE II. Dimensions of Wetland Sub-surface Horizontal Flow.

Parámetro	Symbol	Pilot Wetland Característics	Real Wetland Característics
Flow (m3/día)	Q	2	48
Length (m)	L	2	45
Width (m)	W	0,6	13
Length / width ratio	L/W	3,33	3.46
Depth (m)	y	0,55	0.6
Porosity Dry gravel (%)	n	0,42	0,38
Slope (m/m)	S	0,02	0.05
Surface Area (m^2)	As	1,2	585
Transverse Area (m^2)	Ac	0,033	7.8
Hidráulic Gradient (m/m) Vegetation	G	0,02 Typha	0.05 Typha

Physico-Chemical Parameters and Analytical Methods

● Chemical Oxygen Demand (COD)

The potassium dichromate method was used to evaluate COD levels. This method is a variation of the standard method [19], however, it maintains the basis of it. The variation used has the advantage that it uses a smaller sample and reagents. The sample is chemically oxidized through the action of potassium dichromate at 150 °C for two hours. Silver sulfate is used as a catalyst and mercury sulfate to avoid possible interferences with chloride. Afterwards, determination by spectrophotometry at 600 nm is performed. Equipment and instruments were used to determine the various parameters to characterize the wastewater.

Determination of Chemical Oxigen Demand (COD)-Substrate Relationships

Samples composed by mixtures of water and substrates prepared at different concentrations, and their respective COD was estimated. This test is performed in order to produce a calibration curve and establish a ratio (substrate concentration/COD).

Experimental Methodology

a.   Feed Preparation

These pilot wetlands was fed initially with synthetic wastewater prepared in the laboratory according to the typical characteristics of urban wastewater [22]. This wastewater has an approximate COD of 200-300 mg/L, with the corresponding proportions of nitrogen and phosphorus, in a relation of COD:N:P = 100:5:1. Approximately 200-300 mg of saccharose, 10-15 mg of phosphate hydrogen of potassium, and 50-75 mg of ammonium chloride were added per liter of water.

b.   Operating Modes

The synthetic wastewater was poured into a storage pond of almost 1000 L, Process effluent is collected in a 30 L volume tank, where the samples are taken to be processed. The flow of synthetic wastewater is 2 m3/day.

Description of conventional and innovative output devices.

Conventional Exit Device

The conventional device consists of a PVC pipe 90 mm in diameter and 13 m in length with perforations of approximately 10 mm along its length, for the capture of the effluent (Figure 2). It is located approximately 0.2 m from the bottom of the wetland. The collection of the effluent water is done with a perforated pipe settled on the bottom of the wetland. Then, it is directed towards the exit by means of a syphon, which allows to maintaining the water level inside the wetland.
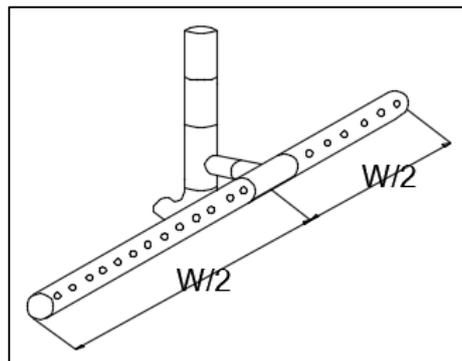

Figure N°2. Conventional outlet device for the effluent of the subsurface flow wetland.

Description of the Innovative device.

The innovative exit device of the artificial wetland, consists of 4 sanitary PVC pipes 90 mm in diameter and 13 m long, located at different heights, in climbing form at 0.15 m and 0.2 m from the bottom of the wetland, with 10 mm perforations in diameter (Figure 3).
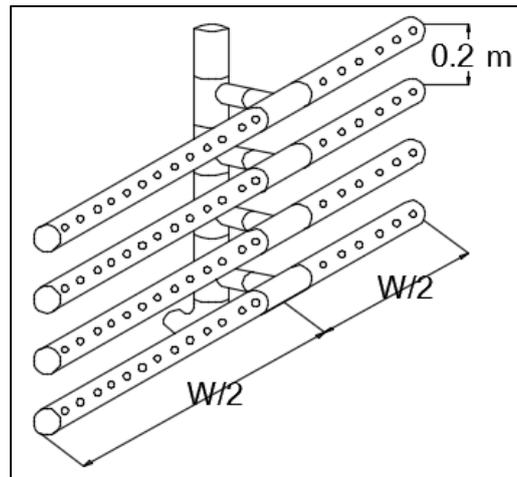
Figure N°3. Innovative outlet device for the effluent of the subsurface flow wetland, Patent Registration Number: 503, INAPI, Chile, February 2018 [23].

Sampling and operation of the constructed wetland

Effluents samples from the artificial wetland were sent periodically to laboratory analysis to measure the chemical oxygen demand (COD) and total suspended solids (TSS), using the standardized method. In parallel, the flow was estimated.

Figure N°4. Effluent and affluent sample

3. Results

3.1 COD-Substrate Relationships

From the experimental values, a straight line with a slope of 1,17 is obtained, as shown in Figure 5, from which it can be stated that the saccharose has a COD per gram, which is above of other organic substances [23]. The model obtained is: Y = 1,1744X.
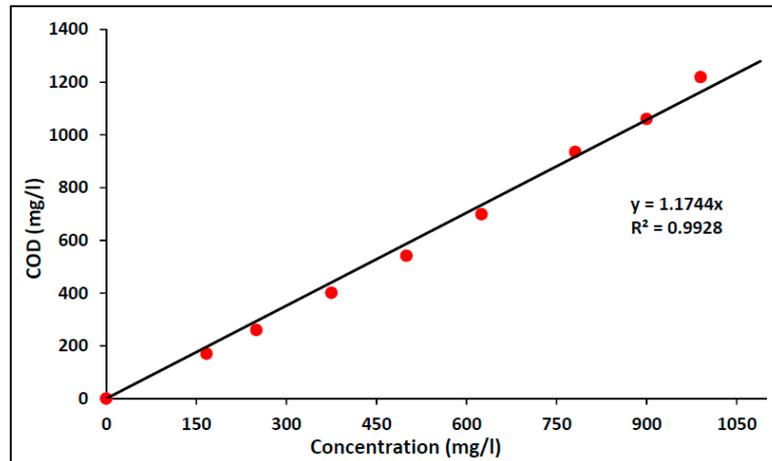
Figure 5. COD-saccharose relationship.

3.2 COD concentration of the artificial wetland

Figure 6 shows the input and output organic matter, using the conventional and innovative effluent capture and evacuation device. Using the COD as an assay, we estimate the abatement efficiency that is reached in the wetland, with better performance when the innovative device is used, exceeding the conventional device by 10%.
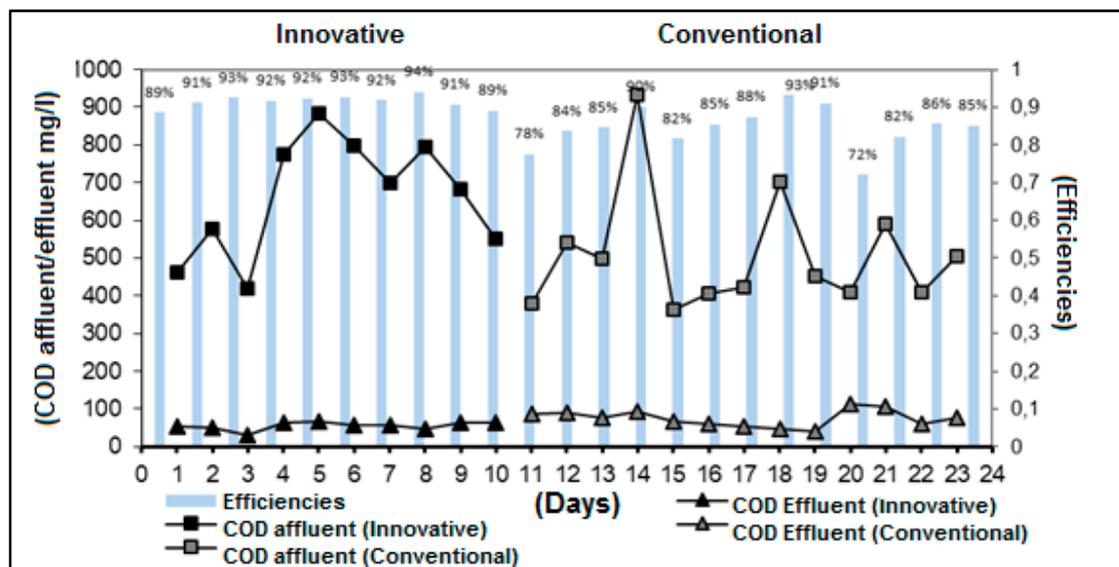

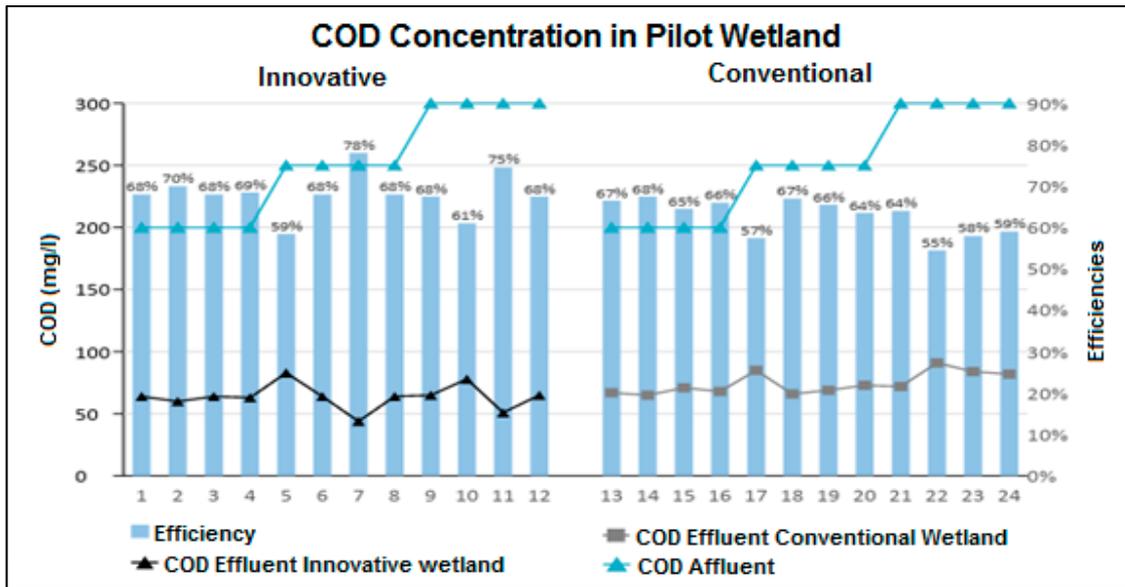Figure N°6. COD concentration in effluent and effluent

Figure N° 7. Efficiency of both devices in the removal of organic matter

3.3 Yields of the wetland with both devices.

Figure 6 shows the yields of the removal of organic matter in the horizontal subsurface flow wetland during the start-up period, with the innovative and conventional device.
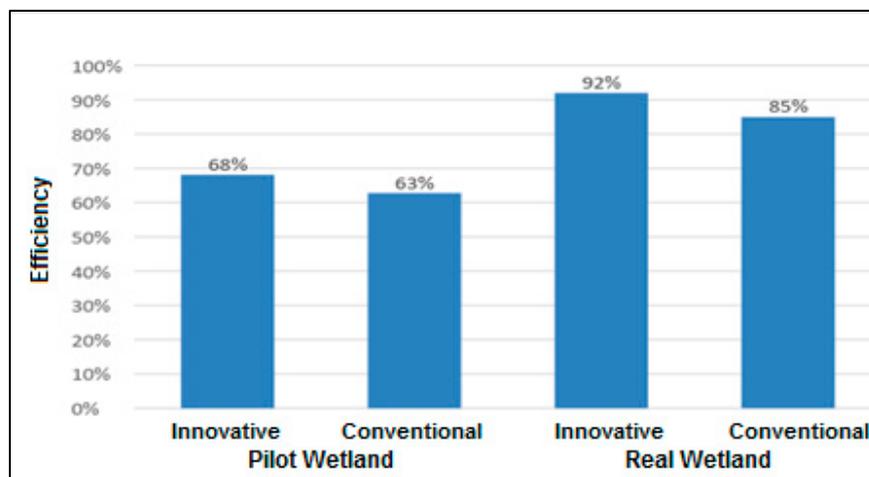

Figure N°8. Average efficiencies of both devices in the removal of organic matter

The higher yields with the innovative device, allows to obtain effluents of better quality with shorter residence times, therefore it is possible to reduce the extension of a wetland for the same treatment horizon, which is based on the efficiency of the innovative device of a 92 %, greater than 85% of the conventional.

The lower efficiency of the conventional device is attributed to the uniqueness and location, which causes the occurrence of preferential flows, leaving an volume with very little water movement, generating a decrease in both the height and effective volume of the wetland.

On the other hand, with the innovative device, having 4 equidistant catchment outlet pipes, it tends to generate a uniform flow that integrally occupies the cross-sectional area, using an effective height closer to the design height of the wetland.

- **Estimation of the useless wetland volume for both devices in Real Wetland**

Given the structure of the conventional effluent outlet device and its capture of the effluent in the bottom, unlike the innovative device that drains the effluent in the entire water column, it is presumed that the water flow behaves according to Figure 7, that explains the difference of efficiency of abatement between both devices.

With the following design equation, the effective heights and volumes are determined; For each effluent outlet device, a flow rate of 48 m3 / day, KT of 1.315 d^{-1}, porosity of 0.35 and average concentrations of effluent and effluent obtained in the laboratory are used.

$$y = \frac{Q*(lnC_a - lnC_e)}{K_T * W * L * n}$$

- **Volume and Effective Height of Treatment in Conventional Device**

The effective height associated with the treatment efficiency of the conventional device is 0.38 m with an effective treatment volume of approximately 201.24 m3, presenting volume loss compared to the theoretical volume in the wetland of 134 m3.
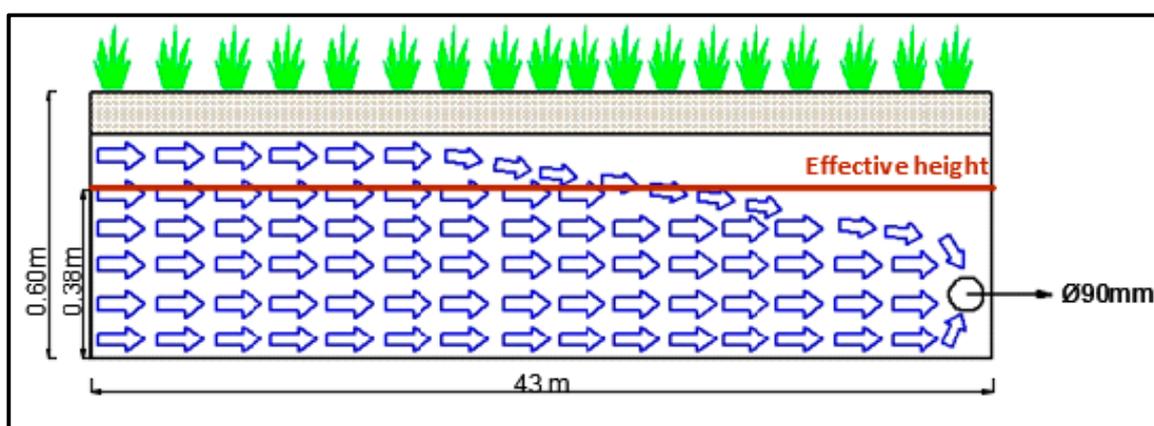

Figure N° 9. Effective height with the conventional device

- **Effective Volume and Height of Treatment in the Innovative Device**

The effective height associated with the treatment efficiency of the innovative device is 0.47 m, with an effective treatment volume of 229.19 m3, presenting a volume loss compared to the theoretical volume in the wetland of 106 m3.
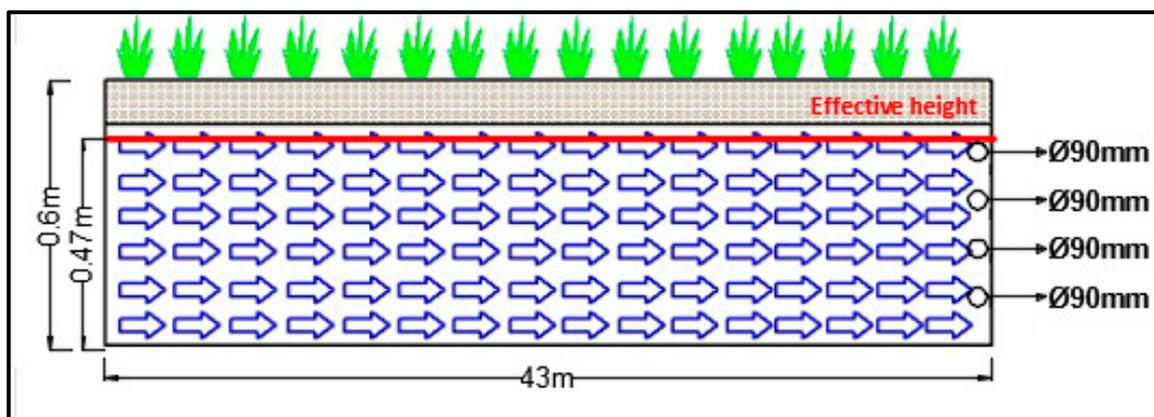
Figure N° 10. Effective height with the innovative device

The innovative device has an effective height higher than that of the conventional device, since it has a greater effective volume, due to the fact that it has a smaller lost volume, associated with the generation of preferential flows.

4. Discussion

[24] applies an artificial subsurface flow wetland for the treatment of wastewater from a cosmetic and pharmaceutical industry, using a system of rooted emergent macrophytes (Cyperus papyrus) for the removal of organic loads, the initial concentration of 92 mg / L of BOD5,20 is reduced to a concentration of 20 mg / L.

The wetland showed a high efficiency in the removal of organic load from the treated water, achieving an average yield of 79% of BOD5,20. While [25] conducted a nine-month campaign for a horizontal subsurface flow wetland, which treats rural wastewater in the Cova Beira region. Initially, the concentrations in the influent were 506 mg / L of BOD AND 677 mg / L of COD and the concentrations in the effluent for BOD and COD were 87 mg / L and 222 mg / L respectively.

The wetland presented a high load removal, where the average efficiencies were 83% for BOD and 68% for COD.

On the other hand, [26] studied the percentage of removal of the organic load of wastewater from a residential building that were treated with artificial wetlands, the sampling was carried out during 25 days at the time of rain and low water

During the sampling carried out in the low season, the initial concentration was 164 mg / L, and after passing through the system, it was 7 mg / L, which means a 96% removal. For the sampling carried out during the rainy season, the initial concentration in the residual water was 306 mg / L and at the exit of the system, 30 mg / L, achieving a 90% removal.

[27] evaluated 18 artificial subsurface flow wetlands planting Stipa ichu. Six of the wetlands were assembled without plants and twelve of them with plants, for the construction they used rectangular plastic containers with measures of 13 cm in height, 33 cm in length and 26 cm in width, and with a hole in the lower part that it collected the effluent. During a period of 10 days of follow-up and with a hydraulic residence time of 35 hours, the COD removal efficiency of domestic wastewater was 92.43% for wetlands without plants and 95.5% for wetlands with plants.

[28] evaluated two wetlands with soil biotechnology plants (SBT). The different plants were classified as Plant I and Plant II. Plant I was controlled for a period of 12 months and an average COD of 266 mg / L was observed in the influent, while the value of the effluent was reduced to 32 mg / L, indicating 87% elimination efficiency. In addition, the BOD efficiency is estimated at 86% with a value

in the influent of 67 mg / L and in the effluent of 9 mg / L. For the wetland with plant II, the initial COD was 118 g / L while that of the effluent was reduced to 31 mg / L, demonstrating 73% elimination. The percentage of elimination of BOD in the system was 72% indicating a moderate efficiency.

[29] it studied the application of halophytic plants in a horizontal subsurface flow wetland constructed for the treatment of domestic wastewater. The pilot plant located in Greece was planted with a polycropping of halophytes (Tamarix parviflora, Juncus acutus, Sarcocornia perrenis and Limoniastrum monopetalum). The results show that the halophytes were successfully developed in the constructed wetland, where, the average BOD concentration of 106 mg / L in the influent was reduced to 39 mg / L in the effluent; with an average elimination of approximately 63% it obtained a removal efficiency for COD of 58%.

In Isfahan, organic matter was removed from the leachate produced in the composting facility by means of a sub-superficial horizontal flow wetland. The study was carried out in two horizontal flow wetlands with the dimensions of 1.5m x 0.5m x 0.5m. One of them was planted with Vetiveria zizanioides and the other wetland remained as control, without planting. They were operated with a leachate flow rate of 24 L / d for more than five months. The control wetland eliminated 21.8% of BOD5 and 26.2% of COD and the other planted with Vetiveria zizanioides eliminated 74.5% of BOD5 and 53.7% of COD [30].

The removal efficiencies of two horizontal subsurface flow wetlands were also investigated by [31]. One of downflow (F1) and the other of upflow (F2), both filled with the hybrid substrate zeolite-slag for the treatment of leachates in rural landfills. During the operation time, the effluents concentrations and chemical oxygen demand (COD) effluents were measured. The results showed that constructed wetlands were able to eliminate the following range of COD, 20.5-48.2% (F1) and 18.6-61.2% (F2).

5. Conclusions

The hydrodynamic behavior of a wetland and its treatment results depend on the form of capture of the effluent.

The form of capture of the effluent of a wetland affects the efficiency of it.

It is observed that the wetland with innovative device presents higher yields than those obtained with the conventional device. By obtaining higher yields with the innovative device, it allows achieving effluents of better quality, which is verified in that the performance of the innovative device has a COD removal efficiency of 92% being superior to the conventional device of 85%, for the case of the full-scale wetland.

The innovative device has a COD removal efficiency of 68% being superior to the conventional device of 63%, for the case of the pilot-scale wetland.

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