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Improved Efficiency of Constructed Wetlands for Oily Water Treatment with Aid of Microbubbles

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The industrial sector has adopted practices for minimize the impacts of large water use on water resources. Among these practices, the treatment of effluents is the most important because ensures that wastewater will be properly disposed and allows its reuse. The constant use of oil in industry causes a significant generation of oily effluents which leads to the need for effective treatment for this type of pollutant. Constructed wetlands (CWs) are systems created for the purpose of treating anthropogenic such as municipal or industrial wastewater. CWs are a cost-effective and technically feasible approach to treating wastewater and runoff for several reasons like low expenses (build, operation and maintenance), operation and maintenance periodic only, on-site labor and water reuse and recycling facilitation. The extremely adaptable sizing of constructed wetlands allows modifications to improve this treatment efficiency. For oily wastewater treatment, CWs filled with floating macrophytes can receive microbubbles nozzles in order to improve the system, increasing the drag of oil to the surface and the supply of oxygen to the aerobic microorganisms. In this work, the increase of the efficiency of oily wastewater treatment in constructed wetlands by addition of microbubbles was evaluated. Computational fluid dynamics (CFD) simulations in the software ANSYS to validate the fluid dynamic behavior of the system. Experimental tests in two constructed wetlands pilot prototypes, with and without addition of microbubbles were made in transparent acrylic. Initial and final concentrations of an oily wastewater in pilot prototypes were determined, as well as essential operation parameters. An oil collector was designed and installed to remove the free oil on the water surface, ensuring the maximum removal of oily waste on constructed wetland prototype. The experimental tests results showed that the final concentration on prototype without aeration was 34.3 mg/L. The final concentration of the aerated prototype was 11.6 mg/L, standing below of the limit of Brazilian Environmental Legislation (CONAMA Resolution nº 430/2011), validating the efficiency increase of the treatment through a simple adaptation.

1. Introduction

The intense generation of effluents is one of the most urgent concerns in the industrial sector. Before proper disposal, this kind of wastewater needs to be adequately treated (Olukanni and Ducoste, 2011). Due to the large use of petroleum derivatives like fuel and lubricant, the industrial sector is a huge generator of oily effluents (Busto et al., 2016). At the end of usual industrial activities, the wastewater may contains oily residues harmful to the public health and to the environment. The incorrect disposal of these effluents cause major impacts to water bodies with changes in pH, BOD, COD and other parameters (Rodriguez-Mateus et al., 2016).
In the last 50 years, the many advantages of constructed wetlands as an effluent treatment methodology have interested many researchers (Pardue et al., 2014). By reproducing the natural environment of water bodies, the constructed wetlands offer a treatment with simple operation and maintenance. Another benefit of this

equipment is its extremely adaptive design, allowing the improvement of the removal of pollutants by changes in physical, chemical and biological processes (Rajabzadeh et al., 2015).
In the treatment of oily effluents, a great adaptation that can improve the efficiency of the wetlands is the sizing of the operation tank like a horizontal continuous decanter. In this way, the equipment will have an improved physical separation by density difference, facilitating the removal of the oil phase (Gila et al., 2016). The addition of microbubbles in the constructed wetlands also promotes improvements in treatment by adding characteristics of a dissolved air flotation (DAF) (Jincai et al., 2013).
Thus, the objective of this work was to investigate the increased efficiency of the removal of oily residues from water due to the addition of microbubbles in a constructed wetland, sized from an analogy with a continuous horizontal decanter. Simulations in CFD and experimental tests in a prototype were used for determine the reduction of the concentration of oil in the effluent.

2. Material and Methods

2.1 Design Criteria

In this work, the Reynolds Number of Turbulence (Re) was used as the design criteria of the constructed wetland. The dimensionless number can be defined by Eq (1) (Ludwig, 1997).

$$Re = \frac{v_c D_H \rho_c}{\mu_c} \quad (1)$$

Where v_c is mean dynamic velocity of the continuous phase (m/s), D_H is the hydraulic diameter (m), ρ_c is the density of the continuous phase (kg/m³) and μ_c is the dynamic viscosity of the continuous phase (kg/m.s). The values of the parameters used to determine the Re are described in Table 1.

Table 1: Parameters used for determination of Re

Parameter	Value
v_c (m/s)	4.34×10^{-4}
D_H (m)	0.8
ρ_c (kg/m³)	8.9×10^{-4}
μ_c (kg/m.s)	1000

Re was also used as a criterion to evaluate the efficiency of the physical separation process (Ludwig, 1997). The predictions for physical separation are described in Table 2.

Table 2: Predictions for Physical Separation

Re	Expected result
< 5000	Little problem
5000 - 20000	Some hindrance
20000 - 50000	Major problem may exist
> 50000	Expect poor separation

The value found for the Reynolds Number was 390.11. It was possible to predict the minimum occurrence of problems in the separation process, affirming the potential efficiency of the proposed design analogous to horizontal continuous decanters.

2.2 Simulations

CFD simulations were performed in ANSYS® 15.0 software (Figure 1) before execution of the experimental tests. Two simulations were performed to evaluate the separation efficiency in wetlands with and without upward flow of microbubbles. The dimensions used in the simulation geometry were the same as in the pilot wetland. The separation efficiency was determined by observing the distribution of the oil phase density in the simulation.

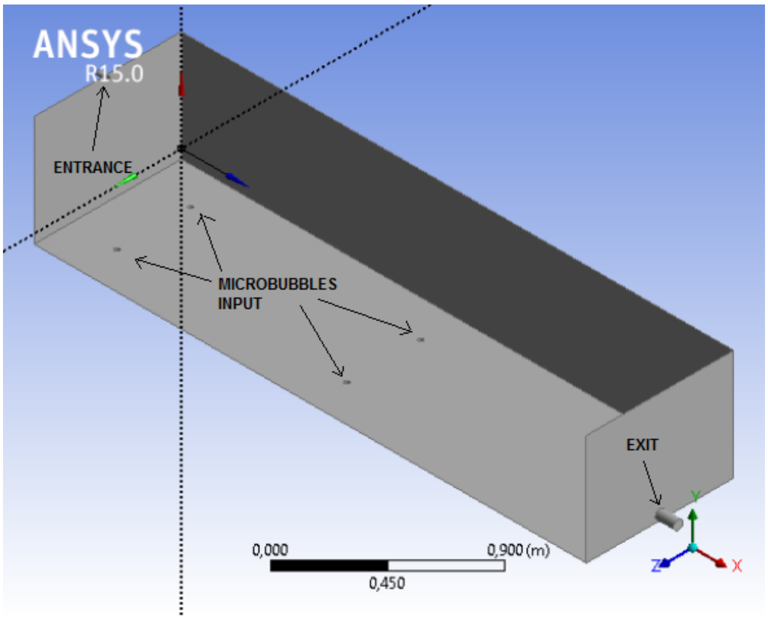

Figure 1: Geometry of constructed wetland simulation on ANSYS

2.3 Description of the prototype

The dimensions of horizontal constructed wetland prototype were 3 m of length, 0.8 m of width, 0.6 m of height and 0.001 m of thickness. The material used was polycarbonate, to facilitate the visualization of the process. The oily effluent was distributed in the pilot wetland through a perforated transverse pipe with 8 orifices of 0.004 m in diameter. After the tests without aeration, the microbubbles were added by two injectors installed at the base of the wetland. The species of macrophytes used in the prototype was *Eichhornia crassipes* also known as water hyacinth. Kawai and Grieco (1983) defined that the maximum efficiency of removal of pollutants occurs when the constructed wetland has 70% of its area filled by water hyacinth. Thus, the 5-day period was set to remove the excess of macrophytes.

2.4 Synthetic oily effluent

The oily effluent was produced with lubricating oil composed by paraffinic, naphthenic, aromatic, polyaromatic and additive hydrocarbons. The oil was mixed with water using a pump for 30 minutes. After the operation, the synthetic effluent showed emulsions and a thin layer of oil on the surface.

2.5 Experimental tests

Two experimental tests were performed before and after the addition of microbubbles. After being filled by water and 30 macrophytes of the *Eichhornia crassipes* species, the oily effluent was introduced into the constructed wetland with a flow rate of 500 L/h. Subsequently, five samples of 70 ml were collected near the entrance of the effluent. After 2 weeks, another five 70 ml samples were collected at the outlet of the treated water. With the end of the experimental tests, the wetland was emptied for the installation of the microbubble injectors and prepared again to be filled with the macrophytes and oily effluent. The microbubbles were produced through a installed 2.0 hp centrifugal pump. The injectors were made with polyvinyl chloride (PVC) tubes and connectors. At the beginning of the operation, five samples were collected at the entrance and exit of the prototype, similar to that occurred in the wetland without microbubbles.

2.6 Analysis of the oil concentration in the samples

The analysis used for the quantitative determination of oils and greases was based on the gravimetric method of section 5520 Oil and Grease - B. Partition-Gravimetric Method of the 20th edition of Standard Methods for the Examination of Water and Wastewater, published by the American Public Health Association (1999). The concentration of oils and greases in the samples was determined by Eq. (2):

$$C = \frac{(A - B) \times 1000}{V_{sample}} \quad (2)$$

Where C is the oil and grease concentration (mg/L); A is the final weight of flask (mg); B is the initial weight of flask (mg); V_{sample} is the sample volume (ml).
Figure 2 shows the constructed wetland filled by macrophytes and oily wastewater.

Figure 2: Constructed wetland prototype

3. Results and discussion

3.1 CFD simulation

The axial distributions of the volumetric fractions of the oil phase in the prototype were simulated. Two hundred hours of operation were simulated in both prototypes, with and without microbubbles.

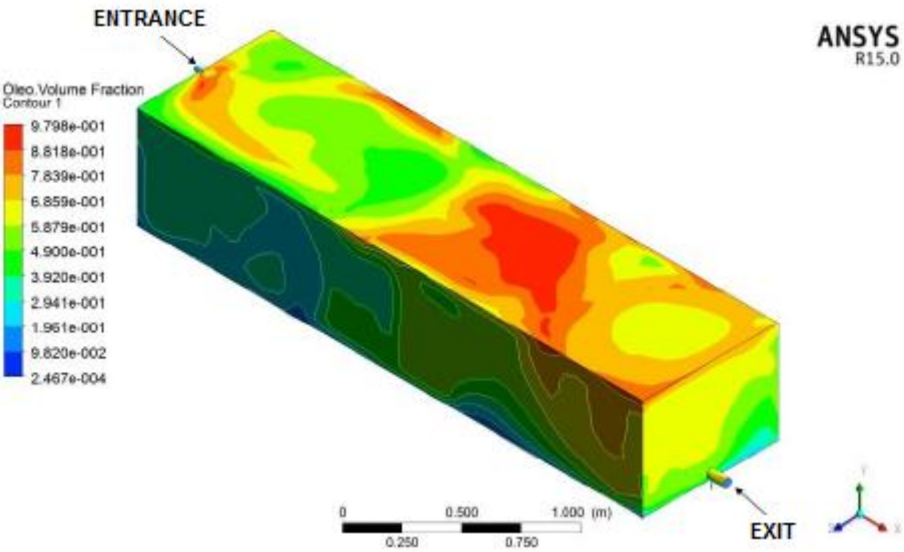

Figure 3: Distribution of volumetric fractions of the oil phase in the prototype without microbubbles

Figure 3 showed that the volumetric fractions of oil did not remain only on the surface of the constructed wetland, being also present in the proximity of the treated water outlet, indicating that the physical separation was not efficient.

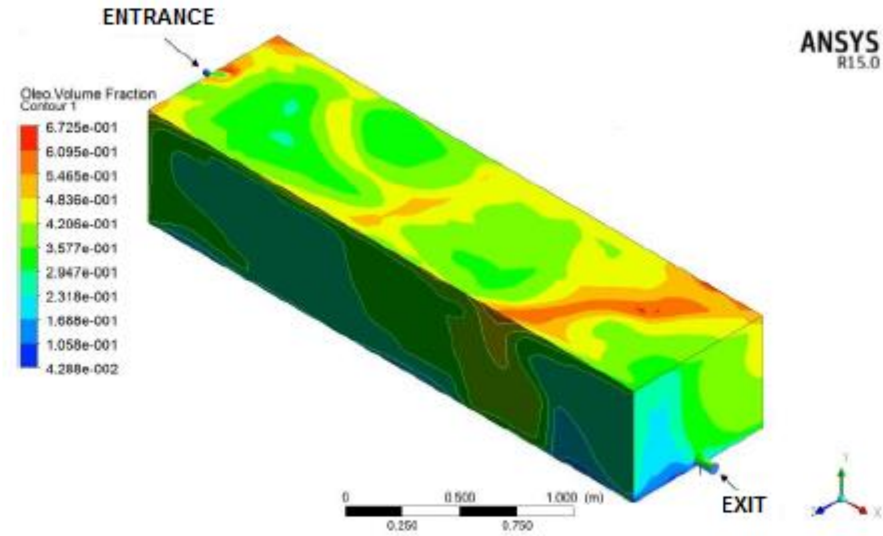

Figure 4: Distribution of volumetric fractions of the oil phase in the prototype with microbubbles

Figure 4 showed that the volumetric fractions of oil were located in the surface of the constructed wetland with microbubbles, far from the treated water outlet. It can be affirmed that the microbubbles can promote the drag of significant fractions of oil, favouring the retention of the residues on the surface.

3.2 Experimental tests in the constructed wetlands

In the beginning of experiment, the oil concentration in constructed wetland without microbubbles was 44,1 ± 0,6 mg/L. After 2 weeks, the concentration of oil was 34,3 ± 2,1 mg/L. Even with the reduction, the final concentration was above the limit established by Brazilian legislation of 20 mg/L of oil in the effluents to be discarded. The oil concentration in aerated prototype was reduced from 45,4 ± 0,5 mg/L to 11,6 ± 1,4 mg/L. The final oil concentration at the exit was below the limit established by Brazilian legislation. The box plot graphic of oil concentrations in prototypes are in Figure 5.

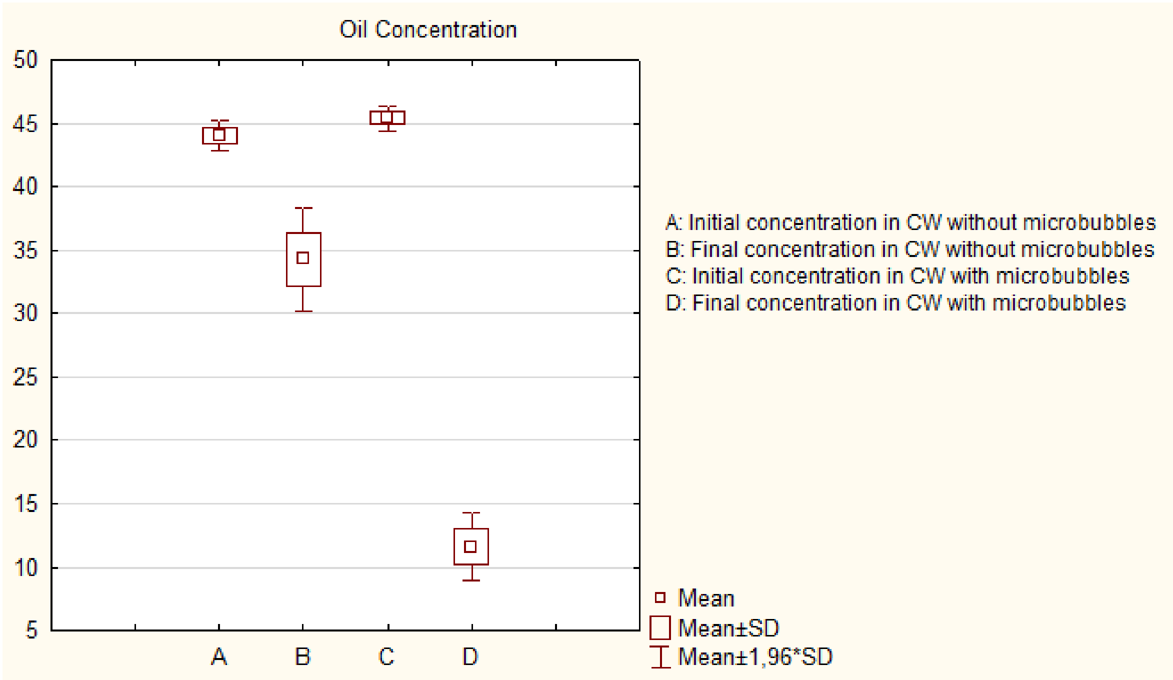

Figure 5: Oil concentrations in CW with and without microbubbles

4. Conclusion

The experiments demonstrated an increase of efficiency in the treatment of oily effluents due to the injection of microbubbles in the constructed wetland, fitting the treated water in the limits required by Brazilian environmental legislation. The experimental tests also validated the CFD simulation, which could predict the improvement of the physical separation in the aerated prototype by the retention of the oil phase on the surface. New studies should be developed to validate the application of constructed wetlands with microbubbles in the treatment of effluents with higher concentrations of oil, to guarantee their application in industries.

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