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EVALUATION OF TREATED SEWAGE DEODORIZATION IN ROOT-ZONE WETLANDS THROUGH DYNAMIC OLFACTOMETRY

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Abstract: The wastewater treatment station (WWTS) by wetlands consists of a physic-biological system with part of the filtering formed by plants and projected according to the filtering soil principle. The elements that constitute the medium, in this case the soil, microorganisms and plants, are responsible for the organic matter and the sewage odor compounds degradation. This study employed the static and dynamic olfactometry methodologies to evaluate the treated effluents odor removal in two stations by root-zone wetlands in rural communities in Irati (PR). Olfactometry results were compared to the effluents physic-chemical analysis, and parameters such as dissolved oxygen (DO), chemical oxygen demand (COD) and pH were taken into account. Results revealed DO increase and COD removal in the treated effluents. Olfactometric analyses pointed to noticeable levels of odor in the treated effluents; however, there was significant reduction in the odor intensity of exit effluents in relation to the entrance ones. In general, the wastewater treatment station through wetlands showed efficient to the removal of odor compounds, as well as the removal or organic matter from the medium.

Keywords: Olfactometry; basic sanitation; sewage treatment; root zone (wetlands).

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INTRODUCTION

In Brazil, basic sanitation services are still rather deficient, mainly in relation to the sewage. In small communities and, especially in regions farther from the urban centers, poor performance of septic systems as well as the high costs involved in the construction of conventional sewage treatment systems, leads to sewage being discharged straight into rivers without proper treatment, interfering in the quality and later use of this water (Verhoeven & Meuleman, 1999).

Andrade Neto & Campos (1999) point out that it is necessary to be aware of the need to apply suitable technology to the Brazilian reality, adopting functionally simple solutions with high benefit/cost ratio. The root zone treatment (wetlands) has appeared as an efficient alternative (Schirmer *et al.,* 2009). In this treatment, besides removing organic matter and heavy metals, there is still the cycling of nutrients and reduction in pathogens existing in the residual waters, thus improving the final quality of the effluent (Ran, Agami & Oron, 2004; Kadlec, 2009). Besides that, in relation to many other sewage conventional treatments, it presents low implementation and operation costs, is easy to maintain, and can be implemented in the local where the effluent is produced (Ayaz & Akça, 2001; Shutes, 2001; Solano *et al*., 2004; Zhou *et al.,* 2009).

According to the literature, constructed wetlands employed to the treatment of residual water and pollution control are classified into two groups: superficial draining systems and subsuperficial draining systems. Between the two systems, similarities are found regarding depuration mechanisms and differences regarding the form and conception (Philippi & Sezerino, 2004; Santiago *et al*., 2005). Due to the inexistence of insects proliferation, the most used method is the horizontal subsuperficial flow system, in which the water level is below the soil level (Barreto, 2005).

The wastewater treatment station (WWTS) by wetlands, is usually installed downstream of a primary treatment septic tank, which is a physic-biological system with part of a filter built with plants (Oliveira & Schirmer, 2009). In this system, plants must be placed on a physical filter structured by a gravel layer. Between the gravel and the bottom layer there is a filtering layer made of sand. Pipes are placed at the bottom of the filter to retain the effluent and take it out the station (Ganske & Zanotelli, 2007). **Figure 1** shows details of the construction of a root zone (wetlands) treatment station.

The WWTS sizing must be carried out according to the influent sewage demand and its performance is influenced by features such as area, length, width, water depth, applied residual water load and hydraulic detention time. The system usually presents efficiency above 90% for pathogens removal, 80% for organic matter and suspended solids, but regarding nutrient removal the efficiency is usually below 60% (Shutes, 2001).

The way residual waters are cleaned in this treatment covers a variety of physical, chemical and biological processes which occur due to the elements that constitute the medium – soil, microorganisms and plants. The cleaning happens in both aerobic and anaerobic conditions, resulting in the release of odor gases. The odor emission might provoke the most diverse reactions, and sometimes characterize environmental uncomfortable situations affecting the quality of life of the population exposed to it (Philippi & sezerino, 2004; Carmo Jr. *et al.,* 2010; Oliveira & Schirmer, 2009; Schirmer *et al*., 2008).

The sensation provoked by the perception of an odor can be considered under four aspects: character, hedonic tone, intensity and concentration (Gostelow *et al*., 2001).

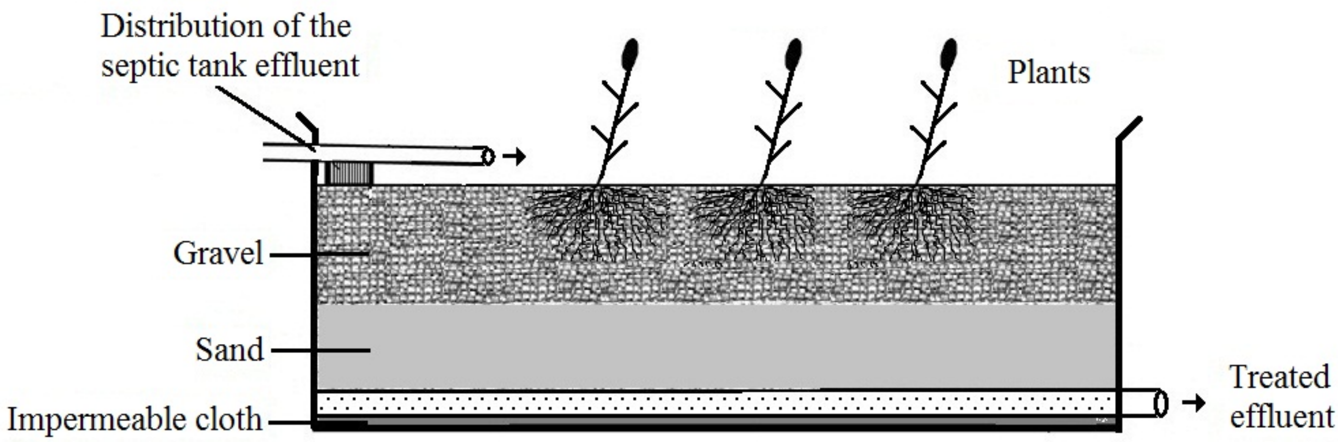

Fig. 1 Root zone (wetlands) WWTS scheme.

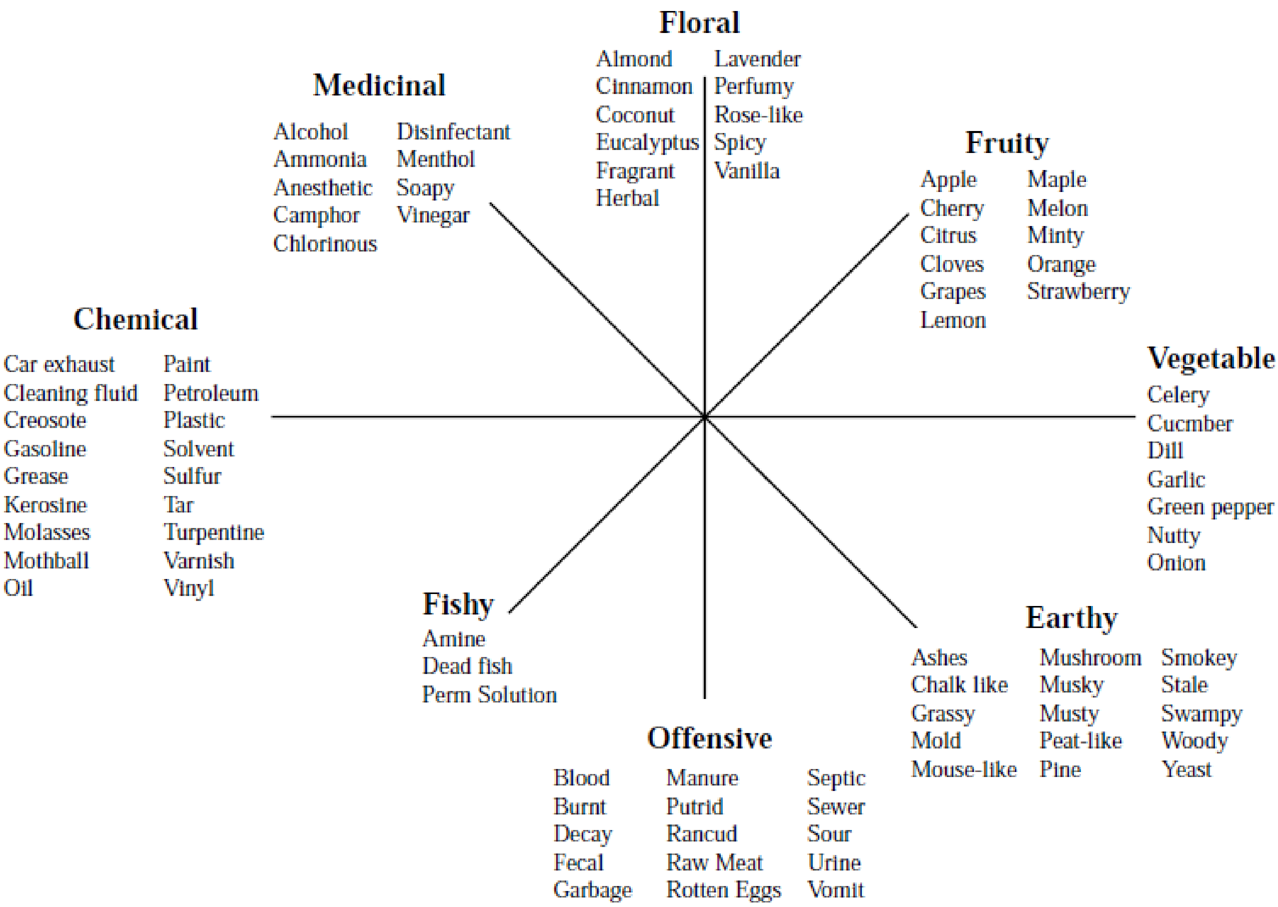

Fig. 2 Odor descriptor wheel (McGinley & McGinley, 2002).

The odorant character (or quality) is a nominal measurement scale (categories). For the characterization of odor, a reference vocabulary for taste and odor sensation is used. The notions are very subjective once the olfaction sensation is individual, although the kinds of response are usually analogous to a homogeneous population (Carmo Jr., 2005; Fernandez, 1997). Amongst the most common forms of representing odor is the Odor Descriptor Wheel, proposed by McGinley & McGinley (2002), in which eight odor categories (families) are easily recognized (**Fig. 2**). From that, the number (or percentage) of responses can be represented in the form of a histogram or graph.

The hedonic value is a measurement of the odor pleasantness; a judgment category regarding how pleasant the odor is, varying from 'extremely pleasant' to 'intolerant'. One way of evaluating the jurors' responses regarding hedonic tone is through the 21-point scale, proposed by McGinley & McGinley (2002):

-10 ------------------- 0 ------------------- + 10
Unpleasant ***Neutral*** ***Pleasant***

The odor intensity noticed is related to the odor strength over the limit of recognition (suprathreshold). The regulation ASTM E544-75 (1997), "Standard Practices for Referencing Suprathreshold Odor Intensity", presents two methods for referencing the odor intensities of a material in the suprathreshold region: the dynamic-scale method and the static-scale method. The static-scale method consists of comparing the odorant intensity of a gas sample with a reference scale made up of a series of 1-butanol solution diluted in water into standard 500 mL wide-mouth, conical Erlenmeyer flasks.

The olfactometer (**Fig. 3**) is nowadays the most recommended equipment to determine the concentration of odorant in gas samples. In this equipment, the sample is continuously mixed with pure air flow to be presented to the jurors (a flow rate mixture occurs, not a volume mixture) through the perception points and olfactometric table (voting table) (**Fig. 4**). This procedure highly increases the possibility of creating different factors of dilution and thus, increases the numeric result accuracy. The olfactometer response is expressed in terms of odorant concentration (Carmo Jr., 2005; Schirmer *et al.*, 2007). The regulation VDI 3882-Part 1 (1992) establishes that the concentration of a certain odorant sample is determined by the dilution with pure air up to the point that the perception limit is reached. The odorant concentration of a certain gas sample is given in OU/m^3 (which reads: odor units per cubic meter of evaluated air), in which, the reference level, 1 OU/m^3 is equivalent to the concentration in which 50% of the jurors notice the odor (olfaction perception limit – K_{50}).

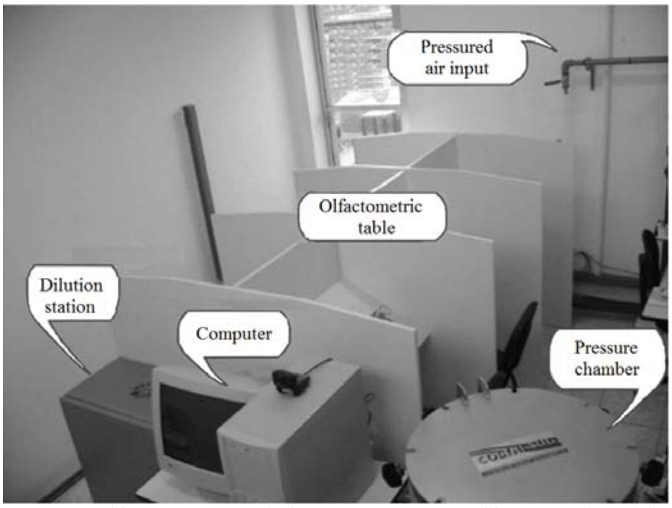

Fig. 3 Olfactometer and its components: olfactometric table, pressure chamber, and computer for data collection.

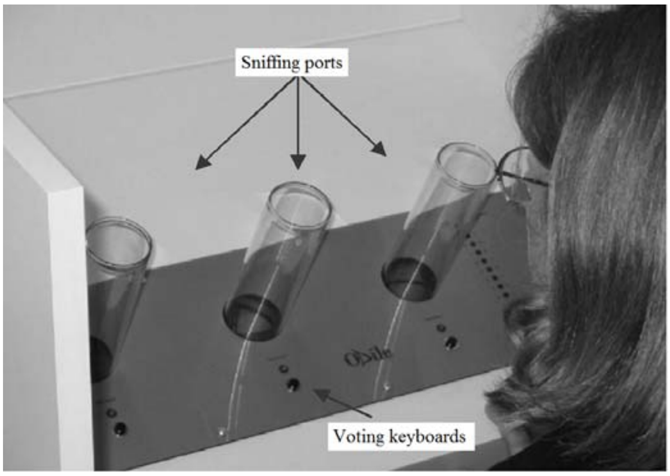

Fig. 4 Olfactometer components: voting table and sniffing ports.

This study uses the dynamic (odor concentration) and static (intensity, hedonic tone, and odorant character) olfactometry as tools to evaluate the efficiency of deodorization of treated effluents in two root zone (wetlands) wastewater treatment stations (RZWWTS) in a rural community in Irati (PR). Physic-chemical parameters as pH, organic matter and dissolved oxygen were also evaluated in order to relate the odorant concentrations found with the effluent conditions prior and post treatment.

METHODOLOGY

Two root zone stations were evaluated, they were both projected according to the entrance effluent demand and located in a rural community of Irati (PR): a station which attends a school, with about 227 children; and the other which attends a house, with five people. The objective, in this case, was to verify whether there were differences in the treatment efficacy between these stations when there was significant variation of flow rate (and, therefore, the load) of treated pollutants.

Both stations were built taking advantage of the septic tank structure already existing in these places and prioritizing the use of low cost material and native plants or ones that easily adapted to the region (in this case, the species *Zantedeschia aethiopica* – calla lily, was adopted). The house station was 1 m deep and 2.3 m wide × 2.5 m long, and was impermeabilized with a three layer 0.2 mm black plastic sheet cover, the physical filter received a 40 cm sand layer, followed by 60 cm gravel layer, which covers the raw sewage distribution pipes in 10 cm. The level difference between the entrance pipes and the exit ones is 10 cm. The school station, however, was 3.0 × 5.0 m width and length, respectively, 1.5 m deep, impermeabilized with a three 0.2 mm black plastic sheet layer, 40 cm sand layer, followed by a 1.10 m gravel layer.

Chemical analyses

Chemical analyses comprised five campaigns between April and September 2011. Each campaign consisted of two samples collection, one upstream (above the septic tank) and another downstream the root zone (wetlands) station. From these, three campaigns were analyzed in order to verify the deodorization through static olfactometry and two through dynamic olfactometry. After collected, effluents were analyzed at the Environmental Sanitation and Water Quality Laboratory at the Center-Western State University; the parameters analyzed were: chemical oxygen demand (COD), dissolved oxygen (DO) and pH. The conservation and sample analysis followed parameters prescribed in the Standards Methods for the Examination of Water and Wastewater (APHA, 1998). Such parameters were chosen due to their relation with odors released by the septic tanks effluents and root zone (wetlands) WWTS.

Olfactometry analyses

Static Olfactometry

The analyses comprised three campaigns, totaling a dozen samples (collected at the entrance and exit of the two stations). When in the laboratory, the containers of effluents were analyzed based on the regulation ASTM E544-75 (1997) in order to determine odorant intensity and according to the methodologies proposed by McGinley & McGinley (2002) to determine the hedonic tone and character. The two campaigns analyses were carried out with a jury composed by 10 people.

Dynamic Olfactometry

The analyses comprised two campaigns, totaling eight liquid samples (collected at the entrance and exit of each station, in both campaigns). These samples were sent to the Air Quality Control Laboratory at the Santa Catarina Federal University (AQCL), in order to determine the odorant concentration of samples. Each

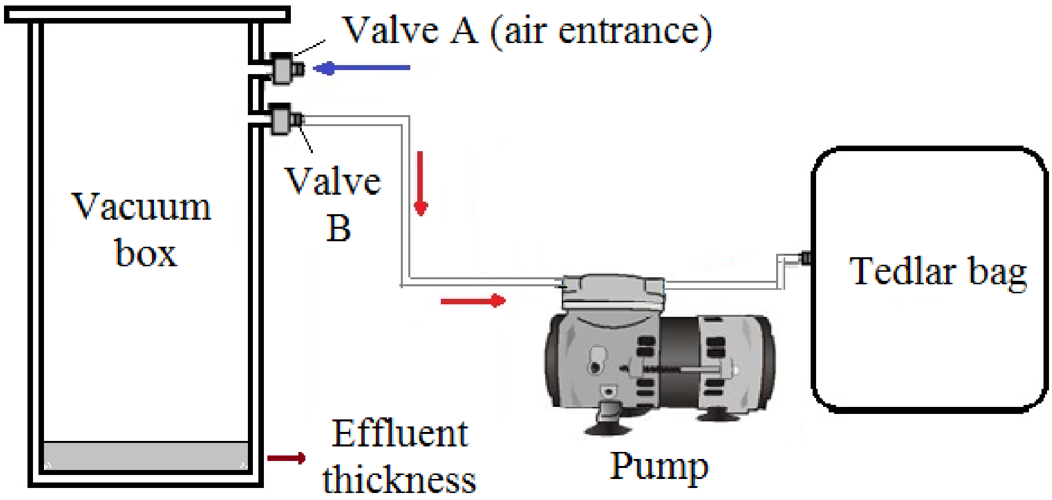

Fig. 5 Air sampling system to the Tedlar bags from the effluents.

(liquid) sample was then placed inside a sealed fiber box[1], with 145 L intern volume, and left for about 10 min until the steady state was reached in the box head space. The head space air contaminated with the partitioned odor from the effluent liquid surface was then transferred through pumping[2] to a 70 L Tedlar® bag, to be analyzed by the olfactometer. From each effluent sample, two samples were collected (replicate). This procedure was carried out with the eight samples, separately. **Figure 5** shows the simplified scheme of air sampling from the two treatment stations effluent.

Once the collection had been finished, bags were sent to the laboratory and the gas effluent analysis was carried out in an ODOTECH olfactometer, model Odile (version 3500) in order to determine the odorant concentrations. The regulations ASTM E679-04 (2011) (United State) and CEN 13.725 (2003) (European Union) based the calculations and the statistic program PROBIT was used exclusively for the statistic treatment of this analysis data.

RESULTS AND DISCUSSION

Chemical analyses of effluents

COD

According to Aquino *et al*. (2006), the chemical oxygen demand (COD) is a parameter used as an indicator of the organic content of residual and superficial waters, largely employed to monitor wastewater treatment stations. The effluent organic load directly influences odor, once, under certain conditions, the partitioning of gases dissolved in water (mainly the most volatile) to the air (Schirmer, 2004). **Table 1** presents COD values obtained throughout the five campaigns.

Table 1. COD results obtained throughout the five campaigns

Collection date	COD (mgO_2/L)					
	Septic tank exit		Wetland exit		% Removal	
	school	house	school	house	school	house
06/04	364	266	95	91	74	66
19/05	450	334	101	150	78	55
21/06	543	423	149	58	73	86
01/08	430	249	159	40	63	84
02/09	418	264	141	40	66	85
Average	441	307	129	76	71	75

Degradation of organic matter in wetlands occurs through anaerobic processes and, mostly, aerobically. Energy and carbon sources for the microorganisms are obtained through oxy-reduction reactions of organic and inorganic compounds present in the effluent (Philippi & Sezerino, 2004). Around the roots, an aerobic zone is formed, in which there is high microbiological concentration, where the organic matter occurs through the heterotrophic bacteria (Naime & Garcia, 2005). At the anaerobic zone, the removal or organic load occurs due to the high capability of anaerobic bacteria decomposition, which occurs in two stages: first when the organic matter is converted into acids and alcohols by acid forming bacteria; and the second when the methane forming bacteria convert organic matter into CH_4, CO_2 and H_2S (Philippi & Sezerino, 2004), being the last one responsible for the characteristic odor.

Average COD removal from WWTS values in both places under study presented 71% removal at the school and 75% at the house, similar values were found in Zhou *et al*. (2009) and Schirmer *et al*. (2009), above 70%. Besides good removal, results presented values that met the limit indicated for the COD parameter prescribed by the Resolution SEMA 001/2007, in which the limit established for domestic effluents treatment is 225 mgO_2/L (Paraná, 2007).

[1] The box size allowed the effluent to form a liquid film of about 2 cm thick at the bottom of the box.
[2] The box had two valves (A and B, according to **Fig. 5**). While valve B was connected to the pump, valve A remained open during the bags filling to compensate the box inside pressure.

DO

Organic matter degradation depends on the availability of oxygen in aqueous medium, making the dissolved oxygen concentration an important parameter in the root zone (wetlands) treatment (Toniato *et al.*, 2005). In aerobic conditions, degradation is the oxidation of organic compounds into inorganic (water and carbon dioxide). Besides that, residual waters with high concentrations of dissolved oxygen will take longer to produce odorant compounds, due to the time taken to reach anoxic conditions (Schirmer, 2004; Oliveira & Schirmer, 2009).

The presence of hydrogen sulfate – the most common among the odorant gases found in the wastewater treatment system – occurs due to competition conditions between sulfate reducing and methanogenic bacteria in anaerobic conditions. When the oxygen is present in the medium, the functioning of sulfate-reducing bacteria is inhibited, though these bacteria might become active and return to anaerobic conditions (Luduvice *et al.*, 1997; Schirmer, 2004, Oliveira & Schirmer, 2009). **Table 2** presents results obtained for the DO parameter.

In superficial flow wetlands, the oxygen supply occurs mainly due to the gas transportation by the plant roots system, through the aerenchyma (Stottmeister *et al.,* 2003; Hench *et al.,* 2003). DO increase in wetlands effluents were also reported by Brix (1997), Costa *et al.* (2003) and Toniato *et al.* (2005), who attributed such effect to the rhizosphere, which releases O_2 to the liquid mass.

pH

According to Schirmer (2004), residual water pH might affect significantly the potential of releasing odorant compounds in the atmosphere. In acid conditions, sulfides and organic acids are easily released, whereas in alkaline pH, ammonia and amines are favored (Luduvice *et al.*, 1997; WEF, 1995). **Table 3** presents results obtained for the pH parameter.

Table 2. DO results obtained throughout the three campaigns

Collection date	DO (mgO_2/L)			
	Septic tank exit		Wetland exit	
	school	House	school	house
06/04	0.55	0.87	4.13	1.92
19/05	0.32	0.17	2.04	1.47
21/06	0.17	0.21	1.42	2.34
01/08	0.18	0.33	1.89	3.40
02/09	0.61	0.23	3.29	6.80
Average	0.37	0.36	2.55	3.19

Table 3. pH results obtained throughout the three campaigns

Collection date	pH			
	Septic tank exit		Wetland exit	
	school	house	school	house
06/04	9.14	7.67	7.63	7.22
19/05	9.12	7.75	8.03	7.13
21/06	9.04	7.79	8.10	7.06
01/08	8.59	8.10	8.03	7.77
02/09	8.78	8.20	8.13	7.75
Average	8.94	7.90	7.99	7.39

H_2S is released, causing odor, only in its molecular form. In neutral pH, there is balance between H_2S and H^- existing in the aqueous phase and, in basic conditions, the formation of H_2S is inhibited, thus controlling the formation of odor due to the presence of sulphur (Gostelow & Parsons, 2001; Schirmer, 2004). pH is one of the most decisive factors also to the efficiency of the nitrification process, which consists of ammonia (odorant) oxidation to nitrate. The nitrifying bacteria use the carbon dioxide and the medium alkalinity as a source of carbon in the synthesis of new cells and oxygen as an electron acceptor during the conversion. The optimum pH band for the nitrification to occur ranges between 7.5 and 8.6 (Ferreira, 2000; Philippi & Sezerino, 2004).

In **Table 3**, it is possible to see that the pH values varied around neutrality and slightly basic, both for the house and the school, which favors the formation of non-molecular forms of sulphur in the liquid medium (and, therefore, non-odorant, such as HS^- and S^{-2}) consequently impeding the formation of odor resulting from the liquid-air partitioning of such compounds.

Results obtained are in accordance to the regulation 357/05 CONAMA, item 34, which establishes values of pH between 5.0 and 9.0 (Brasil, 2005) to the release of effluents.

Static olfactometry

Intensity

Figures 6 and **7** present, respectively, the answers given by the jurors when evaluating odor regarding its intensity at the school and the house.

It can be seen in **Figs. 6** and **7** that the entrance effluents (coming from the septic tank) in both places analyzed revealed intensity ranging between VERY STRONG and STRONG (no answer was given for MEDIUM, WEAK or VERY WEAK). On the other hand, regarding the exit effluents (wetland treated), most of the jurors indicated MEDIUM intensity (10% at the house and 60% at the school), WEAK (70% at the house and 10% at the school) and VERY WEAK (10% at the house and no answer for the school effluent). The

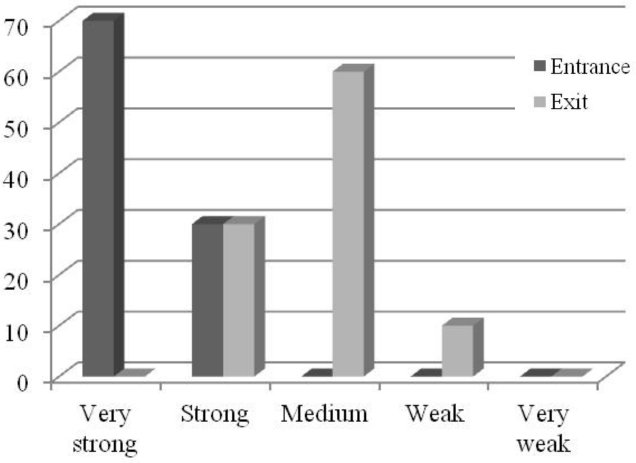

Fig. 6 Answers (in %) given by the jurors regarding the intensity perceived in entrance and exit effluents in the WWTS by wetland at the school.

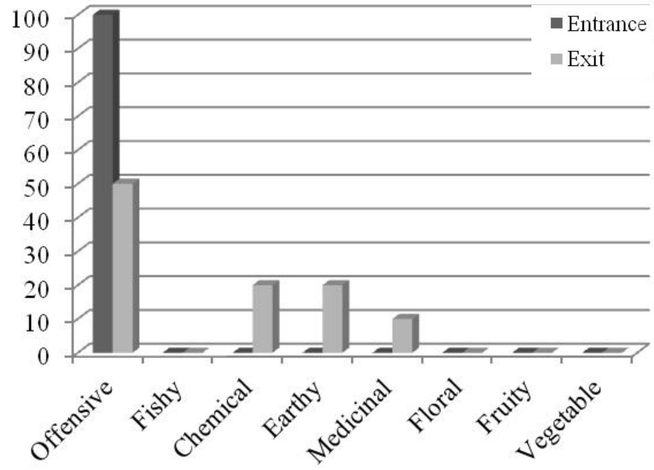

Fig. 8 Answers (in %) given by the jurors regarding the quality of odor perceived of entrance and exit effluents in the WWTS by wetlands at the school.

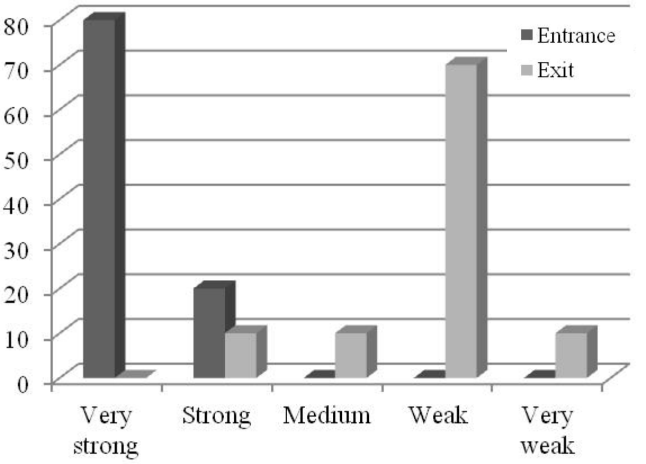

Fig. 7 Answers (in %) given by the jurors regarding perceived intensity in the entrance and exit effluents in the WWTS by wetland in the house.

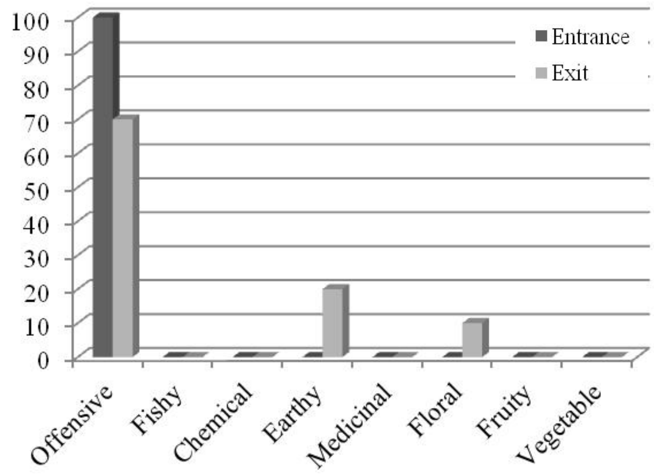

Fig. 9 Answers (in %) given by the jurors regarding the quality of odor perceived of entrance and exit effluents in the WWTS by wetlands at the house.

low percentage of people who considered the perceived odor as VERY WEAK (compared to the butanol scale) justifies the fact that the wetlands treated effluent odor is still noticed, however in a much less representative intensity than the septic tank effluent. This reduction in the intensity occurs, probably, due to the anaerobic degradation, in which the methanogenic bacteria converted fat acid into methane which does not produce smell, and reduces the odor intensity (Oliveira & Schirmer, 2009).

Character

Figures 8 and **9** present, respectively, the answers given by the jurors when evaluating the effluent odor character at the school and the house. For the entrance effluents in the wetlands, for both places sampled, the OFFENSIVE category represented 100% of the answers. In this case, according to the odors wheel proposed by McGinley & McGinley (2002), the most recurrent answers were: rotten eggs, sewer, urine, vomit, manure, putrid, fecal and sour. For the exit (treated) effluents again the OFFENSIVE category was the most signaled, however, with 70% of the answers at the house and 50% at the school, which classified it as: rotten eggs, urine, manure and putrid. The rotten eggs smell was the most cited (both for the entrance and exit effluents); this is probably due to the presence of sulphur in the effluent, which occurs due to the situation of competition between reducing and methanogenic bacteria in anaerobic conditions and whose characteristic is the rotten eggs odor (Luduvice *et al*., 1997; Schirmer, 2004; Oliveira & Schirmer, 2009). Even the Offensive category remaining as the most frequent regarding the treated effluent, it could be seen that significant part of the jurors (30% at the house and 50% at the school) changed their opinions regarding other categories of odor such as EARTHY, MEDICINAL and FLORAL (in relation to the non-treated effluent) supposedly less 'aggressive' in terms of smell.

Table 4. Average of the entrance and exit effluents hedonic tone at the school

Analyses	Number of jurors	Average (entrance effluent)	Average (exit effluent)
1	10	-9.0	-2.6
2	10	-8.7	-2.0
3	10	-9.0	-1.9
	Average of averages	-8.9	-2.2

Table 5. Average of entrance and exit effluent hedonic tone at the house

Analyses	Number of jurors	Average (entrance efluent)	Average (exit effluent)
1	10	-7.6	-0.6
2	10	-8.5	-1.2
3	10	-8.4	-0.8
	Average of averages	-8.2	-0.9

Hedonic tone

Tables 4 and **5** present, respectively, answers given by the jurors when evaluating odor regarding the effluent hedonic tone at the school and the house.

According to the 21-point scale reported by McGinley & McGinley (2002), the average of averages at the school and the house regarding **entrance** effluents in the wetlands were, respectively -8.2 and -8.9, indicating odor close to unbearable (maximum limit, here, -10). The average of averages for **exit** effluents in the wetlands (treated) were -2.2 at the school and -0.9 at the house, which, according to the scale might be considered close to neutrality or slightly unpleasant.

By analyzing the table above, it can be seen that the odor of the treated effluent is less unpleasant than the effluent that comes from the septic tank. This is probably due to the degradation of organic matter by processes of aerobic degradation, which inactivated the action of reducing sulfate bacteria, avoiding the odor formation. Besides that, in anaerobic conditions, fat acids are converted in methane, also influencing the odor hedonic tone (Oliveira & Schirmer, 2009).

Dynamic olfactometry

Table 6 presents results obtained for the odorant concentrations according to regulations ASTM E679-04 (2011) and CEN 13.725 (2003). **Table 6** reveals that all the percentage of odorant concentration removal was above 94% in all samples studied. The remaining percentage (1.8 to 5.3%) allied to the high sensitiveness of the olfactory system make the wetlands exit effluent still noticeable. Results obtained with the numbers of odorant concentration (via olfactometer) confirm the high removal capability (by the wetlands system) of compounds which cause odor and are present in the wastewater treatment stations under evaluation. The mechanisms for removal are the same discussed in the previous sections (aerobic and anaerobic processes of organic matter degradation).

Table 6. Results of olfactometry analyses (odorant concentration) according to regulations ASTM E679-04 (2011) (United States) and CEN:13.725 (2003) (European Union)

	Sample	Source	ASTM [OU m^{-3}]	CEN 13725 [OU m^{-3}]	Reduction [$\%_{ASTM}$]	Reduction [$\%_{CEN}$]
Campaign 1 (month 4)	#1A	Tank exit – school	12,226	12,227	97.6	97.5
	#3A	Root zone exit – school	284	297		
	#2A	Tank exit – house	8,978	10,448	97.1	97.3
	#4A	Root zone exit – house	262	274		
	#1B	Tank exit – school	12,317	13,290	97.6	97.6
	#3B	Root zone exit – school	300	314		
	#2B	Tank exit – house	8,659	9,341	95.8	95.9
	#4A	Root zone exit – house	361	377		
Campaign 2 (month 5)	#5A	Tank exit – school	8,301	8,624	94.8	94.7
	#7A	Root zone exit – school	433	459		
	#6A	Tank exit – house	13,788	14,320	97.9	98.2
	#8A	Root zone exit – house	288	258		
	#5B	Tank exit – school	8,040	8,670	96.9	96.9
	#7B	Root zone exit – school	244	272		
	#6B	Tank exit – house	9,555	10,913	97.7	97.4
	#8B	Root zone exit – house	222	289		

(*) Indicators A and B of samples refer to the duplicates (same effluent).

CONCLUSIONS

In a wastewater treatment station by wetlands, the organic matter degradation, as well as pH and the availability of oxygen in the medium contribute directly to the control of odorant compounds formation.

Analyses through static olfactometry revealed that, although the intensity of wetlands treated effluent was reduced when compared to the tank effluents, effluents treated in both stations by wetlands still present enough odor to be noticed, even if with lower intensity. In the dynamic olfactometry analysis, all treated effluents evaluated presented percentage of odorant concentration removal above 94%. Thus, results allow the conclusion that the treatment of effluents via root zone (wetlands) is a viable and promising alternative, presenting low cost of implementation and operation, easiness of maintenance and good efficiency in odor gases reduction.

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