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Odor assessment tools and odor emissions in industrial processes

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ABSTRACT. Environmental odors are an inherent part of any given process and can frequently be a cause of public environmental discomfort. Brazilian regulations are now characterizing odors as a form of air pollution and state that odor discomfort on surrounding populations must be avoided by industries. No olfactometry-related technology is standardized or even recognized. This makes it vital to create a federal reference, at least methodological, on the subject. Thus, the present work had the objective to apply, adjust, and evaluate the results of different olfactometric techniques in three types of industries which are known as odorous. The points of most significant odor emission to wastewater treatment plants were located at the system inputs. The techniques that were used are based on international standards and regulations. In all case studies, the applied odor assessment methods (odor intensity, quality, hedonic character and concentration) were found to be satisfactory for representing the odor situation. The method presented in this paper for evaluating the hedonic tone proved to be very convenient. These methodologies allowed for the results to be presented in a numerical form, providing with objective results from subjective analyses.

Key words: air quality, atmospheric pollution, odor, olfactometry.

RESUMO. Ferramentas para avaliação de emissões odorantes em processos industriais. Os odores ambientais sempre fazem parte de uma situação ou processo, provocando as mais diversas reações, e por vezes caracterizam situações de desconforto ambiental em uma toda população. A legislação brasileira, em âmbito nacional (alguns Estados), apresenta os odores como uma forma de poluição ambiental, onde o desconforto à população vizinha de potenciais emissores deve ser evitado. Atualmente, no Brasil, nenhuma metodologia relacionada à Olfatometria (medida da resposta de um júri a um estímulo olfativo) é padronizada ou mesmo reconhecida. Nesse sentido, o presente trabalho tem como objetivos aplicar, adequar e avaliar resultados de diferentes metodologias olfatométricas (baseadas em normas internacionais vigentes) em fontes odorantes distintas, quais sejam: refinaria de petróleo, estação de tratamento de efluentes domésticos e indústria papelreira. São casos práticos, aplicados a três indústrias fortemente marcadas pela natureza odorante de seu processo, que mostraram a importância da utilização de uma ferramenta desta natureza na melhoria da qualidade do ar nas comunidades vizinhas a estas unidades. Nos três casos avaliados, as metodologias empregadas na caracterização do odor (intensidade, qualidade, hedonicidade e concentração do cheiro) representaram de modo bastante satisfatório a real situação dos odores para cada estudo de caso, nos períodos em que foram realizadas as amostragens.

Palavras-chave: qualidade do ar, poluição atmosférica, odor, olfatometria.

Introduction

Environmental odors are inherent parts of most industrial processes; they may provoke an array of reactions, frequently becoming a cause of public environmental discomfort. When addressing complaints by the local population, the largest problem faced by environmental agencies and industries is the lack of adequate odor standards to guide both authorities and industry representatives

to correctly assess the odorous impact and classify the different odor sources within the industrial site. Among the types of environmental pollution, odors are amongst the hardest to regulate due to the subjective nature of an odor's nuisance. Based on that principle, authorities are impeded to move forward with public complaints, unless when odors are happening simultaneously to other forms of air pollution, regulated by law. For that reason, odor regulations only exist in a few countries.

Historically, odor perception in the vicinity of industrial plants has been a cause of concern for both neighbors and environmental authorities. According to Kaye and Jiang (2000), odors represent more than 50% of public environmental complaints to regulatory agencies. Despite the growing concern on this matter, few studies on odors have been done in Brazil. Increasing emission control is expected, following an international trend. Thus, the adoption of more rigid emission limits (specific for each type of industry) and the inclusion of odor measurement and control programs are expected to be more enforced (LACEY et al., 2008).

In general, odors are a result of the interaction between organic (typically volatile organic compounds, most of them emitted from industries and vehicles) or inorganic (mainly sulphur and nitrogen) compounds and the body's olfactory system, once odorants are capable of triggering the neurological system. This interaction causes impulses which are then transmitted to the brain (BELLI FILHO; LISBOA, 1998; PROKOP, 1986; SCHIRMER et al., 2010; LACEY et al., 2008).

Odor characteristics

The sensation caused by an odor perception can be categorized under three aspects: character, hedonic tone and intensity.

Odor character

The odor character (or odor quality) is measured in a nominal (categorized) scale. In this case, odor characterization occurs through the use of a reference vocabulary of odorous sensations. The notions involved are highly subjective, since the olfactory sensation is individualized, although answer types are generally analogous in a homogeneous population (CARMO JUNIOR et al., 2005; LACEY et al., 2008). Thus, it is a complex task to describe the odor character of a sample or location, since it should represent the perceived odor according to a reference list of known odors. In that sense, the extent of a jury's 'odor vocabulary' will influence the results. The odor wheel is amongst the most common forms of odor character representation. It was described by McGinley and McGinley (2002) and contains eight odor categories (or odor families) that are easily recognized: floral, vegetal, fruity, medicinal, chemical, offensive, earthy, fishy. The odor wheel is widely used in odor assessment studies.

Odor intensity and odor concentration

The perceived intensity of an odor is relative to its strength beyond the odor perception limit. The American standard ASTM E544-75 presents two

methods to assess odor intensity: the dilution method (static or dynamic dilution) and the static scale method.

Static Dilution Olfactometry: The static dilution method consists of the dilution of a certain sample volume in a pre-defined volume of pure air. The pure air must be lacking any substance that may mask the sample's odor. This method is not very practical, since a number of sterilized recipients are required for each dilution step, under controlled pressure conditions.

Dynamic Dilution Olfactometry: The dynamic dilution method requires a dynamic-dilution olfactometer (Figure 1), which is the most recommended equipment to estimate the odor concentration of a sample. In this case, the sample is continuously mixed with a pure air flow for the jury presentation. Thus, in dynamic-dilution olfactometry there is a mixture of air flows, as opposed to air volumes. This technique increases the possibility for the creation of different dilution factors and, consequently, the precision of the numeric results. A dynamic-dilution olfactometer's precision is intimately dependent on the precision of the mass flow controllers that regulate the flows of pure and odorous air.

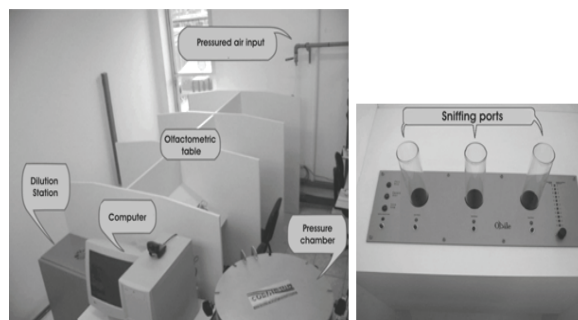


Figure 1. The olfactometer and its components; in detail the sniffing ports.

The olfactometer's results are expressed in terms of odor concentration. The standard practice VDI 3882 - Part 1 (VDI, 1992) establishes that the odor concentration of a sample is determined by the dilution factor in which the odor perception limit is attained. The odor concentration of a gaseous sample is expressed in OU m^{-3} (odor units per cubic meter). As a reference, 1 OU m^{-3} represents the odor concentration in which 50% of the jury perceives the odor and 50% does not. This situation is also defined as the odor perception limit.

In the specific case of sampling in point sources (e.g.: a stack), the odor emission rate (OU h^{-1}) is the product of the gas flow rate (in $\text{m}^3 \text{ h}^{-1}$) and the odor concentration. The odor flux ($\text{OU h}^{-1} \text{ m}^{-2}$) can be determined when measuring the odor emission

from a solid or liquid surface. For that purpose, sampling is performed using a flux chamber over the surface, and the odor concentration results are multiplied by the ratio between the air flow running through the chamber and the surface area that the chamber covers (CARMO JUNIOR et al., 2005; SCHIRMER et al., 2005).

Static Scale Olfactometry: Odor intensity can also be evaluated through the butanol method (also known as the static scale method), which consists of a comparison of the odor sample and synthetic samples that serve as a reference scale. These synthetic samples consist of a diluted reference substance (e.g.: n-butanol) in air or water (PERRIN, 1994). This evaluation is performed according to the ASTM E-544-75 standard (ASTM, 1997). Another method for determining odor intensity is described by the standard practice VDI 3882 – Part 1, in order to evaluate the odor intensity of a given sample, the jury should express their odor impression according to the scale presented in Table 1.

Table 1. Odor category scale.

Odor	Intensity level
Very strong	5
Strong	4
Average	3
Weak	2
Very weak	1

Source: VDI 3882 - Part I (VDI, 1992).

In synthesis, the static scale method has the advantage of presenting low cost and the ability to be conducted in any given location (considering that all that is required is a set of 1-butanol bottles in those pre-defined dilution rates). Its limitation consists basically of the impossibility to provide a precise numerical result that expresses the odor concentration, which is only possible with the use of an olfactometer. On the other hand, dynamic-dilution olfactometry can be considered less practical and more costly, since it requires specific equipment and installations. With this method it is also necessary that the samples are collected in containers that do not interact with odors (such as Tedlar® or Teflon® bags) and taken into the lab for analysis within a relatively short period of time (a period of 30 hours is suggested by the EN:13.725 European standard).

Odor hedonic tone

The hedonic tone is a measure of an odor's pleasantness. The dichotomy pleasantness/unpleasantness associated to an olfactory sensation can vary between 'extreme pleasantness' and 'extreme intolerance'. This is a very subjective

notion, because the olfactory sensation is highly individualized. Factors such as: psychological and health state, culture, habits and age can influence odor perception. Yet, the answer types are generally analogous for a homogeneous population (CARMO JUNIOR et al., 2005; LACEY et al., 2008; MCGINLEY; MCGINLEY, 2002). The final result is obtained from the average response of the jury. McGinley and McGinley (2002) proposed a 21-point scale to register the jury's response to an odor's hedonic tone:

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

Odor legislation in Brazil

Some state regulations prohibit the emission of odorous compounds in levels that will be perceptible outside the industry's property limits. These regulations include air quality standards with concentration limits for 55 odorous compounds of known perception threshold.

Up to today, the only legislation that determines odor emission limits in Brazil is the SEMA 41 (PARANÁ, 2002) state regulation, from the state of Paraná. It defines that odor generating activities that emit more than 5×10^6 OU h⁻¹ (odor units per hour), have to install an odor treatment equipment of at least 85% efficiency for odor removal. On a federal level, the Conama 382 resolution (BRASIL, 2007), determines that "according to the local characteristics of the surroundings of the odorous source, the licensed environmental agency may establish more restrictive emission limits, considering the impact that the odors may cause beyond the industrial zone".

Materials and methods

Samples were collected using an indirect sampling technique, known as the 'lung principle'. The Tedlar® bag, connected to the source through a urethane tube, is inserted into a Fiberglass chamber, and a vacuum pump is used to create negative pressure inside the chamber, thus pulling the sample into the bag (Figure 2). Through this technique, only the sampling tubes and bag are in contact with the sample. On humid/warm days or on odor sources with elevated humidity, the sample is run through an Erlenmeyer immersed in ice to promote condensation and avoid condensation inside the Tedlar bags. It is assumed that relative humidity will not affect the results so long as it remains below 100% (no condensation).

A 13-person jury was selected using the butanol technique (Table 1). No smokers or persons with head colds or other respiratory conditions that could influence their odor perception were allowed in the jury. Persons were also advised not to eat or drink (except for water) for a period of one hour before the analysis. They were also advised not to wear strong perfumes or colognes.

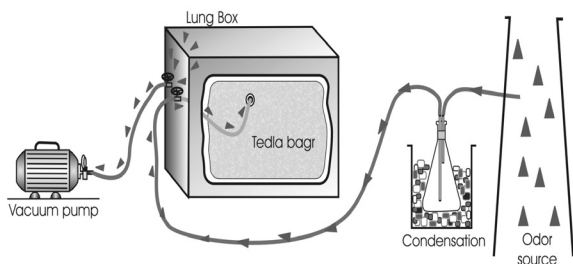


Figure 2. Sampling method in Tedlar bag by 'lung principle' with humidity removal.

Odor intensity analysis

Odor intensity was evaluated according to the ASTM E-544-75 (ASTM, 1997) standard. The jury was instructed to sniff and memorize the sample and then to smell the reference scale, and then to pick the butanol bottle that best represented that odor's intensity. One of the difficulties in this method is to best train the jury to discern between the intensity of an odor and its other characteristics, such as the hedonic tone. The fact that the butanol scale has an alcohol scent may confuse some of the jury members when the sample's odor has a very different character. To avoid that, it is necessary to be as clear as possible during jury training.

Odor hedonic tone analysis

The 21-point arbitrary scale that was proposed by McGinley and McGinley (2002) was used to register the hedonic tone responses. Each member of the jury was asked to grade the odor's hedonic tone using one single value from this scale.

Odor concentration analysis

To determine the odor concentration, a dynamic-dilution olfactometer was used (model Odile, Odotech Inc.). Analysis followed the methods suggested by the European Standard EN:13.725 (CEN, 2003). Figure 3 shows the olfactometer's voting ports during an analysis.

Each cabin has a voting board with three sniffing ports, as can be observed in Figure 3. Dilutions were presented in descending order at a step of 1.58. Jury members are oriented to press the button beneath the port from which they

believe the diluted odor is coming from. The software performs the continuous analysis of the jury's responses and the final result is the calculated average of the members' results. The American ASTM and the European CEN standards have a few differences in these calculations, so that results are not always the same.



Figure 3. Olfactometer with a jury member.

Case studies: application of olfactometric methods

In this article, three case studies are presented. These case studies were performed in order to test the olfactometric analytical procedures and also to characterize the odor emissions and the olfactory nuisance in three different locations:

- the wastewater treatment station of an oil refinery;
- a domestic wastewater treatment plant (WWTP);
- a recycled paper plant;

In the first two case studies, the following odor assessment tools were applied: odor intensity; odor hedonic tone; odor concentration. In the recycled paper factory, odor concentration was the only parameter investigated. Different jury members were used for each sampling campaign for a wider spectrum of responses.

In the oil refinery, samples were collected in two campaigns, during the morning period, when the weather was mostly sunny. In the first campaign, the average temperature was 18°C; wind speed was 1.94 m s⁻¹. During the second sampling campaign, air temperature was 20°C, and the wind speed was 1.82 m s⁻¹. Sampling points were the following: P1: System Input; P2: Water/oil separation tank; P3: Located between the stabilization pond and the aerated equalization tank.

The domestic WWTP was also sampled in two campaigns, both during the morning period. In the

first campaign, the sky was mostly clear and the average air temperature was of 18°C. During the second sampling campaign, skies were also clear and the average air temperature was 20°C; the average wind speed was 4.1 m s⁻¹. Each sample was analyzed by a jury of 13 members. To provide with the odor profile in the WWTP, five sampling points were chosen, each in a treatment stage, as follows: P1: Screening; P2: Denitrification and aeration tank; P3: Sludge gravity tank; P4: Sludge Press; P5: System outflow (end of treatment). Soon after the first sampling campaign, the sludge press was deactivated, so the second sampling campaign did not include this point.

The recycled paper plant case study presents an odor diagnosis performed in a plant located in southern Brazil. Odor concentrations were measured using a dynamic dilution olfactometer (Odotech's Odile®). In all three sampling dates, the skies were clear, and the average temperature was 28, 26 and 25°C, respectively. The sample locations were the following: rubber tank (sampled in the morning period), primary settling tank, and four exhaust stacks. The wind speed was not measured here because samples were taken directly from the stack.

Results and discussion

Oil refinery case study

In the oil refinery case study, results for the intensity, hedonic tone and odor concentration are shown in Table 2.

Table 2. Results for the odor intensity, hedonic tone and concentration analysis.

Sampling campaign	Point	Odor Intensity	Hedonic Tone	Odor concentration (EN:13.725), OU m ⁻³
1	P1	strong/very strong	-3.6	-
	P2	strong/very strong	-2.4	-
	P3	strong	-2.5	-
2	P1	strong/very strong	-5.0	4,652
	P2	strong/very strong	-3.0	1,451
	P3	average	-2.4	881

Sampling points P1 (system input) and P2 (water/oil separation tank) were considered the most important from the point of view of the emitted odors. Although these two locations presented the same odor intensity level (strong/very strong), P1 was considered more unpleasant by the jury (average hedonic tone of -3.6 and -5.0 in the first and second sampling campaign, respectively).

At P3, the hedonic tone results were similar to P2, although this analysis produced a few extreme

data, as can be seen in the data box plot (Figure 4A and B). This behavior is considered normal due to the subjectivity of this analysis.

According to the data showed in Figure 4, for the first sampling campaign, there were no inconsistent data for P1; the highest value was + 3 and the lowest was -10. Inconsistent data were observed for P2 and P3 samples. Notably, the median is the same for all three sampling points.

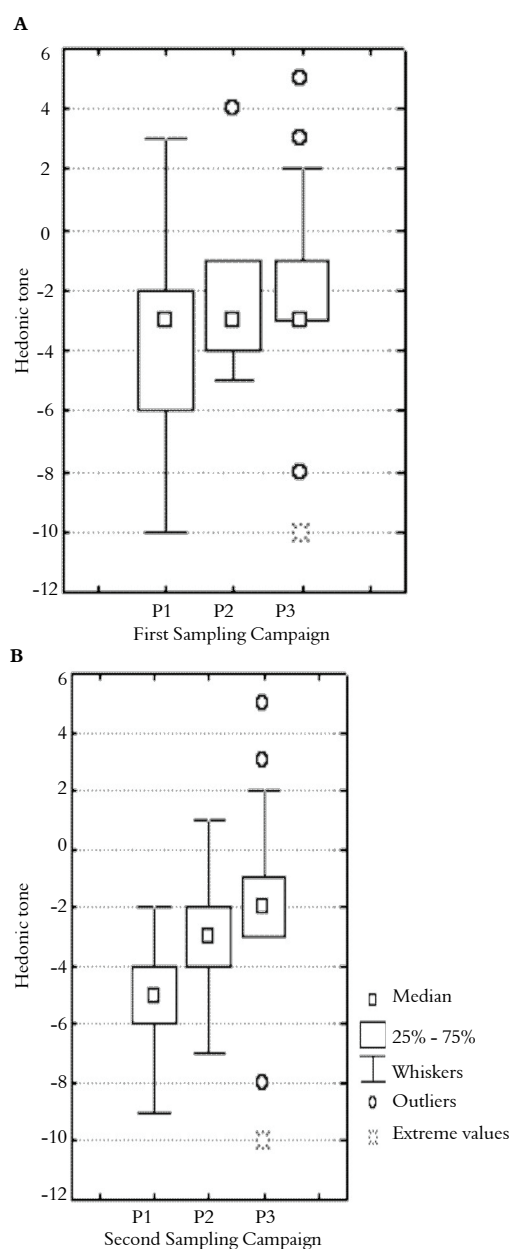


Figure 4. Box plot for the hedonic tone data obtained in both sampling campaigns.

On the second sampling campaign, P1 still presented the lowest average hedonic tone, proving its importance in the odor profile of this location. P3 presented more inconsistent data than other two

sampling points. The odor concentration analysis was performed on the second sampling campaign, because only then the recently purchased olfactometer was installed and running. The odor concentration for P1 was of 4,562 OU m⁻³; the sample had to be diluted 4,562 times with clean air, until 50% of the jury could not perceive any odor, and 50% still could. This means that the odor perception limit was reached at 4,562 dilutions. Odor concentration at P2 was of 1,451 OU m⁻³ and 881 OU m⁻³ at P3.

P1 (the system's inflow point) presented the highest odor intensity and lowest hedonic tone. The pre-treatment stages are generally the main source of odors in WWTPs, so that the greatest part of odor problems in these plants can be mitigated with measures to minimize their synthesis in the early stages of wastewater treatment.

Domestic Wastewater Treatment Plant (WWTP)

The results for the intensity, hedonic tone and odor concentration in the domestic WWTP are shown in Table 3.

Table 3. Results for odor intensity, hedonic tone and concentration.

Sampling Campaign	Point	Odor Intensity	Hedonic Tone	Odor concentration (EN:13.725), OU m ⁻³
1	P1	very strong	-9.5	47,740
	P2	weak/average	-2.5	295
	P3	average	-3.8	337
	P4	average/strong	-5.3	797
	P5	weak/average	-2.8	415
2	P1	very strong	-9.1	32,798
	P2	average/strong	-3.8	667
	P3	average	-2.4	482
	P4	-	-	-
	P5	weak/ average	-2.2	353

Odor intensity data was similar in both sampling campaigns for P1, P3 and P5. In P2, there was an increase in odor intensity in the second campaign, and odor was also considered less pleasant, which suggests a connection between the two parameters. Figure 5 shows the box plots of the hedonic tone data in all sampling points for the second campaign.

Most authors state that an odor concentration of 1,000 OU m⁻³ is not considered very strong. Strong odors would be those presenting concentrations higher than 1,000,000 OU m⁻³. It was noted that the highest odor concentrations in this case study did not reach that level, but was still considered strong and highly offensive by the jury.

For each exhaust, the outflow rate was measured and multiplied by the odor concentration to obtain

the odor emission rate, in OU h⁻¹ (odor unit per hour). The total air outflow of the equipment # 4 is the added flows of all four exhaust stacks (29.72 m³ s⁻¹ or 106,992 m³ h⁻¹).

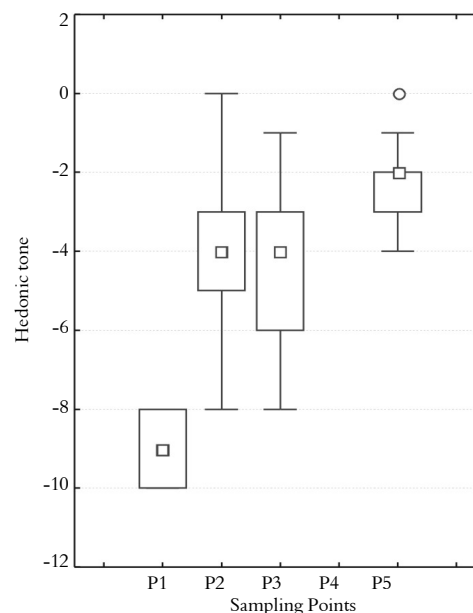


Figure 5. Box plot of the hedonic tone levels in all sampling points.

Recycled paper factory

Results for odor concentration and emission for the recycled paper plant are shown in Table 4.

Table 4. Results obtained for the recycled paper factory.

Sampling location	Sample	Odor Concentration (EN:13.725) OU m ⁻³	Standard Deviation (log)	Emission flow rate (m ³ s ⁻¹)	Odor emission rate (OU h ⁻¹)
Rubber Tank	1	1,056	0.36	-	-
	2	761	0.25	-	-
Settling Tank	1	276	0.32	-	-
	2	750	0.33	-	-
Exhaust 1	1	1,658	0.2	7.80	46,556,640
	1	3,445	0.27	8.34	103,432,680
Exhaust 2	2	1,162	0.24	-	34,887,888
	1	1,292	0.42	7.66	35,628,192
Exhaust 3	2	1,503	0.38	-	41,446,728
Exhaust 4	1	4,873	0.31	5.92	103,853,376

This company is located in the state of Paraná, where the state regulation SEMA 054 (PARANÁ, 2006) states that odor generating activities, with emission rates larger than 5,000,000 OU h⁻¹ must install odor treatment equipment that should be previously analyzed by the Environmental Institute of Paraná and must have at least 85% efficiency for odor removal.

As can be observed in Table 4, all exhaust stacks had considerably higher odor emission rates than what is permitted by the environmental agency in

that state. The company was advised by the authors and has since then installed equipments to reduce their odor emissions.

Conclusion

All three cases evaluated (oil refinery, recycled paper plant and domestic WWTP), the effluent input had the highest values for odor concentration and/or intensity, once there the effluents present a high concentration of organic matter (most of them odorant). Analogously, the point of less importance in terms of odor emission is the final outflow of the wastewater treatment plants.

The main difficulties found in the application of these methodologies refer to the jury members: the jury's lack of concentration required the trainer's constant attention and repetition of the explanations. Olfactory sensitivity was found to be highly variable, and intimately connected to the jury's emotional state. On the other hand, the proposed jury selection methods were sufficient to remove persons that had difficulty discerning different odor dilutions.

The butanol scale was used as a tool to select the jury members. Jury members that passed this test were considered apt to work at the dynamic-dilution olfactometer, since the olfactometer also presents samples in discrete dilutions. On the other hand, this method did not test the jury's focusing skills, or if their olfactory sensitivity would change during the olfactometric analysis. To better chose the jury members, the method proposed in the EN:13.725 standard seems to be more adequate. Through this method, the jury is evaluated in 10 different occasions, in 3 different dates, thus testing their ability's consistency.

The method presented in this paper for evaluating the hedonic tone proved to be very convenient. Jury members did not show difficulty in attributing a grade to the perceived odors. Another positive aspect of this method is the fact that the output is a numerical value, providing an objective result from a subjective analysis.

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