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A Critical Evaluation of the Influence of Different Panel Composition in the Measurement of Odour Concentration by Dynamic Olfactometry

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Odour concentration expressed in terms of OU_E/m^3 by using the dynamic olfactometry analysis, standardized by the European Norm (EN) 13725 are by now the most commonly and worldwide accepted method to measure odours. The EN, first edition published in the year 2003, is actually under review process by the WG2 of the CEN/TC246 and the end of the revision work is expected for the year 2018. Related to the odour panel the standard fixes some parameters (e.g: panel size). Nothing is, however, performed about the composition of the panel members in terms of their gender, the age of the involved persons and their origin and nationality. Also the current literature is limited to discussing how the measurement of emission rates derived from the same odour source could be related to the panel composition.
The scope of this study is to investigate the influence on the determination of odour concentration with dynamic olfactometry, according to EN 13725 standards, applying different panel conditions, with the objective to define the optimal criteria to evaluate the odour concentration and obtain the highest repeatability and accuracy of the sensorial measure.
A critical evaluation was carried out in relation to the same odour source with the comparison of the different panel composition (in terms of gender, age and nationality) to measure the odour concentration. In the experimental studies the measurements were conducted within 5 h after sampling to reduce the variability of the mixture and increase the reliability. All assessors who participate in odour measurements were qualified and tested according the quality criteria assurance foreseen by the EN13725. Studies were taken considering real environmental odour emissions collected at a wastewater treatment plant (WWTP).
The results obtained show a not significantly influence of the investigated characteristics of the single panel member in the repeatability assurance of the measure of the odour concentration by dynamic olfactometry. While a variation of the results in terms of OU/m^3 is demonstrated related to the different nationality and biological factors (age and gender) of the assessors. There is therefore the need to consider these factors in the current odour determination practices, for example in calculating the uncertainty factor of the measurement.

1. Introduction

Odour emissions from industrial plants represents a nuisance for the exposed community and cause of numerous complaints (Zarra et al., 2008). The abatement of odour pollution is a problem that can no longer be postponed, to guarantee an environmental and social sustainability of the industrial plants. Between the different odour assessment methods, the sensorial analysis by dynamic olfactometry represents at the state of the art the method most widely used and utilized by all involved actors in the environmental odour issues (Hove N.C.Y et al, 2017).

Dynamic olfactometry is actually the only odour measuring method standardized by an European Norm and officially accepted in the most countries that deal and have regulations in environmental odour (Brancher et al., 2017).
With dynamic olfactometry it is generally defined the method with which is measured the concentration of an odour in terms of Odour Unit per cubic meter (OU_E/m^3) using an olfactometer as dilution apparatus and qualified panelists for the odour detection (EN1375:2003).
Odour quantification by dynamic olfactometry is applied in all of the odour management phase: measurement, characterization, control and monitoring. The determination of odour concentration by dynamic olfactometry is normally applied to assess the odour impact, to design and select the best odour reduction technology, to quantify the odour abatement, to analyze odour complaints, to validate odour measurement technologies (Zarra et al., 2008; Munoz et al., 2010; Belgiorno et al., 2012). The need for an adequate, objective and repeatable method to measure odour concentration, defining also the uncertainty of the method is thus a key point to be able to consider the method useful to compare different scenarios (Boeker et al., 2008; Capelli et al., 2010; Zarra et al., 2014).
The European Norm 13725 in his actually version, published in the year 2013, after a long working process started in the year 1991, has the objective to provide a standardized method in order to guarantee a common basis for evaluation of odour emissions in the member states of the European Union. The Norm describes the characteristics and requirements of the method, the technical equipment and the odour assessors.
Over the years, studies and research carried out on dynamic olfactometry have highlighted the various factors of uncertainty that influence the method (Van Harreveld, 1999). Uncertainty factors that can be classified as instrumental (related to the dynamic olfactometer (McGinely et al., 2006; Higuchi, 2009)), sensorial (due to the human assessors (Capelli et al., 2010)) or methodological (linked to the number of analysis round, dilution classes, choice of the used method – forced or yes no – (Hove et al., 2017)).
In relation also to the attempt to reduce the factors of uncertainty of the method, in 2012 the Working Group 2 (WG2) of the CEN/TC264 'Air quality' was reactivated which aims to revise the EN13725 in the view of the several research conducted on this topic. The WG2 includes international experts that participating on a voluntary basis, representing European Accreditation member organizations from 9 countries (Van Harreveld A.P., 2014).
The present work provide an extensive investigation of the influence on the determination of odour concentration with dynamic olfactometry, according to EN 13725 standards, of the different panel member characteristics. The influence of the gender, age and nationality of the involved persons for the panel is analysed and discussed. The scope of the research is to improve the repeatability and accuracy of the sensorial measure, defining the optimal criteria to evaluate the odour concentration.

2. Materials and methods

2.1 Odour samples and experimental program

Research studies were carried out considering real environmental odour samples collected at a full-scale wastewater treatment plant (WWTP). The investigated treatment plant has a conventional activated sludge treatment and operates with only domestic sewage.
For the experimental activities, odour emissions were sampled from the same odour source at the secondary sedimentation treatment units of the investigated plant. The secondary sedimentation treatment unit consists of a circular tank characterized by a diameter of 45 m and a total volume of 3360 m^3.
Air samples are taken according the EN 13725:2003, using the 'lung' technique. Nalophan® sampling bags with 20 liters volume were used for the sampling.
Sampling activities were conducted for two consecutive weeks, taking one sample a day, excluding Saturday and Sunday. A total of ten sample (C_i; i = 1 – 10) were taken for each investigated sources over the monitoring period. All samples were analyzed with dynamic olfactometry to calculate the odour concentration (OU_E/m^3).

2.2 Panel composition and selection criteria

A number of twenty-four assessors were employed in the experimental studies. All panel members are tested prior to their participation in an olfactometry panel according the EN13725 standard verifying their quality assurance requirements based on the n-butanol standard odorant. A certified calibration gas of 50.1 ppm n-butanol in nitrogen (SIAD SpA, It) was used for the tests.
All conducted analysis confirm for each panelist that the Odour concentration of n-butanol at its detection threshold should be between 20 and 80 ppb as specified in the European standard. One "European Odor Unit" is 123 mg n-butanol (40ppb) by definition.

Table 1 reports the details of the investigated characteristics of each involved EN-qualified assessors considered for the study.

Table 1: Characteristics of the EN-qualified assessors

ID	Gender	Age	Nationality	ID	Gender	Age	Nationality
1	Male	44	Italian	13	Male	26	Japanese
2	Male	35	Italian	14	Male	25	Japanese
3	Male	26	Italian	15	Female	24	Japanese
4	Male	39	Italian	16	Female	23	Japanese
5	Female	29	Italian	17	Female	46	Philippine
6	Female	33	Italian	18	Female	38	Philippine
7	Female	32	Italian	19	Male	31	Philippine
8	Female	29	Italian	20	Male	30	Philippine
9	Male	26	Italian	21	Female	23	German
10	Male	27	Italian	22	Female	23	German
11	Female	28	Italian	23	Male	25	German
12	Female	26	Italian	24	Male	25	German

2.3 Dynamic olfactometry analyses

To measure the odour concentration in terms of OU_E/m^3, a calibrated, 4 ports olfactometer with yes-no presentation mode, Model TO8 (Ecoma GmbH, D) was used. Analyses were carried out at the Olfactometric Laboratory of the SEED (Sanitary Environmental Engineering Division) research centre of the University of Salerno, adopting a number of three consecutive rounds. All the measurements were conducted within 5 h after sampling to reduce the variability of the mixture and increase the reliability (Zarra et al., 2012). Each collected samples were analyzed by all 24 CEN-qualified assessors, by composing the 4 panel member in randomly manner. For each samples 6 panel (P_y; y = 1 – 6) of 4 assessors were carried out, randomly constituted.

2.4 Datasets and statistical analyses

A data sets of 720 thresholds (10 samples x 3 dilutions rounds x 24 assessors) and of 60 odour concentrations (10 samples x 6 panels) for the considered odour class (secondary sedimentation) were analyzed to investigate the influence of the individual characteristics of the panel member on the repeatability and accuracy of the odour concentration measured by dynamic olfactometry.
All variables were seen as categorical variables, namely the variable gender consisted of the classes “male” and “female”; the age analyzed trough the 3 classes “0-25” (master students), “26-32” (doctoral students) and “33 and over” (teaching and technical staff); and the nationality were represented by the four classes “Italian”, “Japanese”, “Philippine” and “German”.
The influence of the different investigated variables of the panelist member on the repeatability (r) of the measurement of the odour concentration by dynamic olfactometry and their interactions was calculated according to EN13725, using the following equation:

$$r = t \cdot \sqrt{2} \cdot s_r$$

where t is the student *t* distribution for the 95% confidence level, and s_r is the standard deviation of the test measurements. The effects were studied considering a significance level of 0.05 ($p < 0.05$) and the results were compared according to the EN repeatability limit ($r < 0.477$) (McGinley et al., 2006; Hove et al., 2017).
While to investigate the influence of the considered variables on the results in terms of OU_E/m^3 of the olfactometric measurement, for each assessor, the average percentage deviations of the individual measures were calculated with respect to the result of the overall panel for the single campaign. The media of these values on the single campaign for all ten campaigns were then calculated, for each assessors, to defining their overall percentage variance. These values of the considered assessors were finally attributed to the various categories of groups of investigated variables in relation to the study to be done (e.g. for the analysis of the "gender" group: "male" equal to 12 values and "female" equal to 12 values) (see Table 1)) and then compared to each other.

3. Results and discussions

3.1 Effects on the repeatability of the different characteristics of the assessors

Figures 1 presents the results of the investigations in terms of repeatability (r) of the influence of the gender ("male", "female"), age groups ("0-25", "26-32", "33 and over") and nationality ("Italian", "Japanese", "Philippine" and "German"), respectively.

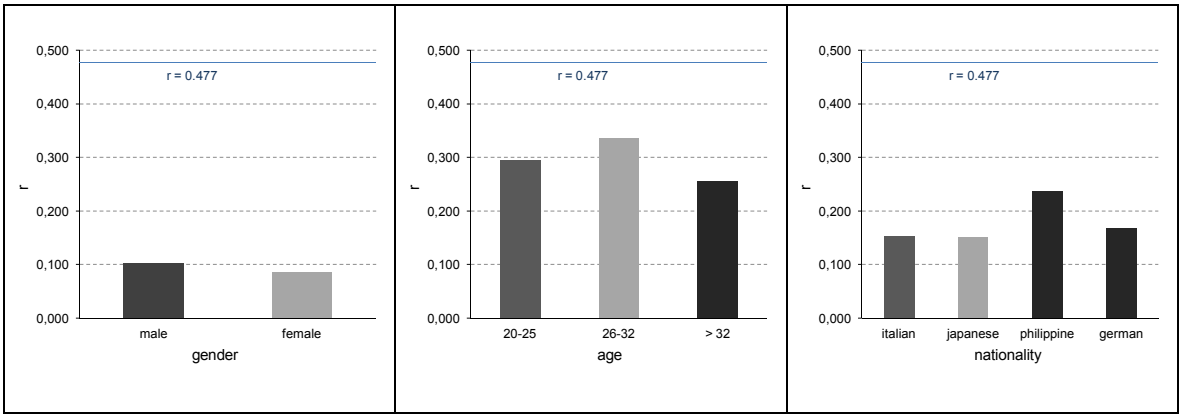

Figure 1: repeatability (r) values calculated for the considered classes of the investigated different groups of variables (left: gender; middle: age; right: nationality) of the assessors.

Results show how all calculated values of r for all investigated classes, considering the maximum t-student values of the different combination, are less than the limit value fixed by the EN13725 as accuracy and precision criteria, equal to 0.477. The values of the calculated *r* show small variations between classes of the groups "gender" and "age", while a more difference is highlighted in the "nationality" group, only with reference to the "philippine" class respect to the other investigated classes.
The analysis of the interaction between the considered variables of each investigated panel member characteristics group applying the Student t-test highlights, furthermore, that none of the variables considered is statistically significant for the test under examination. All calculated t values are in fact well below to those tabulated considering $p < 0.05$ and the correspondence number of degrees of freedom.
Based on these results, for the investigated odour classes, it is possible to assume that the different gender and age of an individual EN-qualified assessors not improve significantly the repeatability, while at the contrary the different nationality of the assessors composing the panel can have small effects.

3.2 Effects on the result in terms of OU/m^3 of the different characteristics of the assessors

Figure 2 shows the geometric mean of the threshold values detected by each EN-qualified assessors and the result in terms of OU/m^3 (Cod) calculated considering each of the six panels of four assessors in the three rounds (P_y; y = 1 – 6), in the single sampling campaign (C_i; i = 1 -10) for the overall experimental period.
Results show a detected odour concentration for all analyzed samples between 38 – 724 OU/m^3.
Calculating the average values of the percentage variations (%varCod_{med}) expressed in absolute value, of the geometric mean of the threshold values detected by each EN-qualified assessors with respect to the result of the panel of four assessors in the three rounds (Cod) and considering the overall experimental period, the assessor identified with the ID number 1 highlighted the lowest value (equal to 10.43%) while the ID19 the highest value (equal to 28.27%).
Table 2 presents the influence of the groups of the considered variables and their relative classes, on the quantification of the odour concentration in terms of %varCod_{med}. The values are determined with reference to the all conducted 10 sampling campaigns.
The results showed that the considered variables influenced the final result of the calculated odour concentration (OU/m^3) with an average percentage variations expressed in absolute value around 17%. The influence of the different groups are comparable, ranging from the highest value of 17.68% calculated for the group "nationality", to the lowest value of 17.36% determined for the group "age". Between the different classes of the investigated groups the "Philippine" displayed that with the prominent influence, while the "Japanese" prove to be the most reliable.
The optimal criteria to evaluate the odour concentration by dynamic olfactometry and obtain the highest repeatability and accuracy of the sensorial measure was found by using female assessors, with age over 33

years and of Japanese nationality. While the poorest accuracy is obtained by male assessors, with an age between 26 – 32 years, and coming from the Philippines.

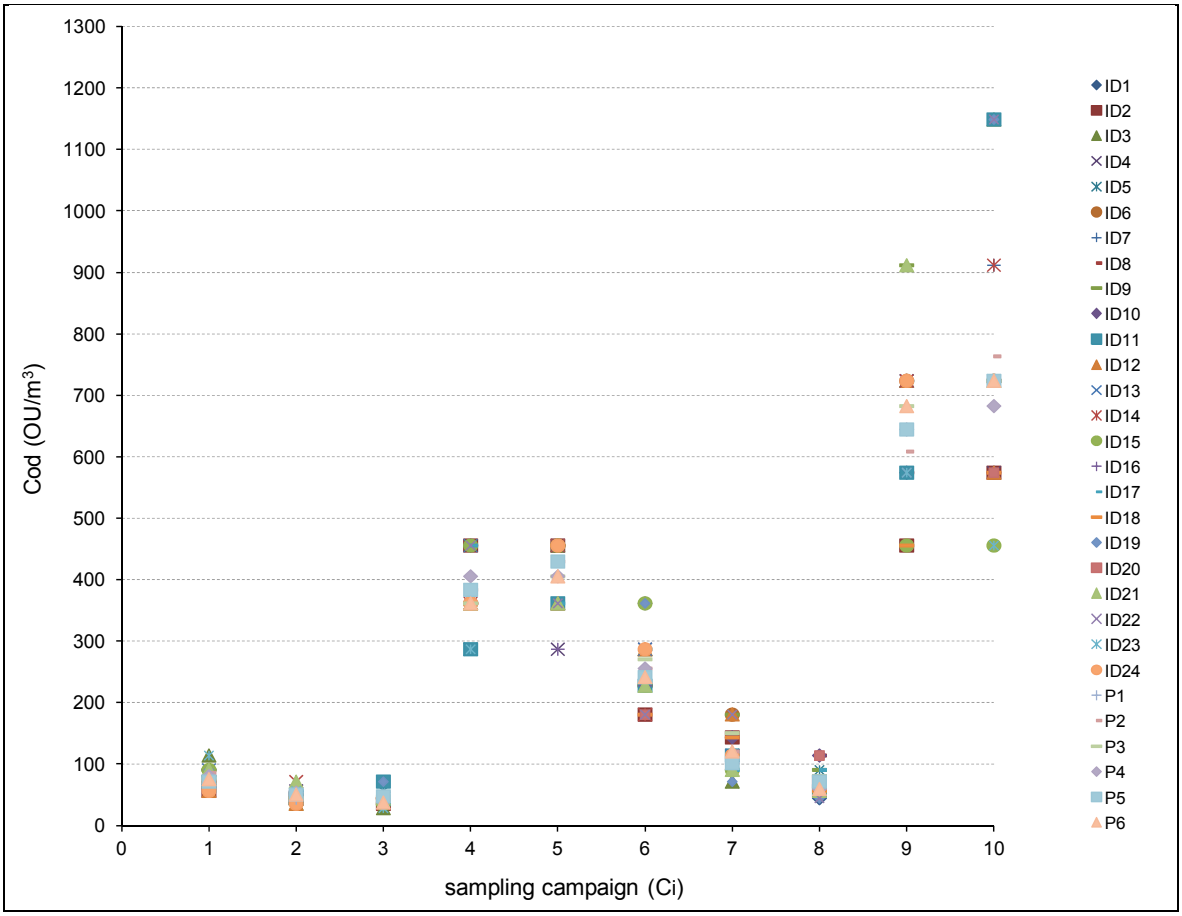

Figure 2: geometric mean of the odour thresholds detected by each assessors and relative calculated odour concentration for each campaign.

Table 2: Influence of the considered variables on the result in terms of odour concentration

Variable	$\%varCod_{med}$	Variable	$\%varCod_{med}$
Gender	***17.47***	***Nationality***	***17.68***
Male	18.06	Italian	17.25
Female	16.88	Japanese	15.72
Age	***17.36***	Philippine	19.34
0 - 25	17.82	German	18.41
26 – 32	18.27		
> 32	15.99		

4. Conclusions

Laboratory tests were carried out to evaluate the influence on the determination of odour concentration with dynamic olfactometry, according to EN 13725 standards, of different panel member characteristics. Three different groups of variables and relative classes were investigated (gender ("male" and "female"), age ("0 - 25 years", "26 - 32 years" and "33 years and over") and nationality ("Italian", "Japanese", "Philippine" and "German")) considering a panel group of 24 EU-qualified assessors. The tests were conducted with reference to real environmental odour emissions samples collected at the secondary sedimentation of a full-scale wastewater treatment plant. The effects of the different characteristics of the assessors on the repeatability of the olfactometric measurement and on the results in terms of OU_E/m^3 were studied.

Results of the effects on the repeatability show how all calculated values of r for all investigated classes of the three investigated groups of assessors characteristics are EN-fulfilling. Of the three tested variables of the assessors, the “gender” and the “age” not improve significantly the repeatability. While the different nationality showed the highest effect. Results of the effects on the OU_E/m^3, by analyzing the influence of the different investigated groups and of their considered classes, underline an average percentage variations expressed in absolute value around 17% for all investigated variables. Between the different groups and classes of the investigated variables the “nationality” group with the “Philippine” class has been determined as the one with the highest effect (19.34%), while the “Japanese” prove to be the most reliable (15.72%).
The paper provide information for all operators involved with dynamic olfactometry to taken into account the effect of the panel member composition on the repeatability quality assurance of the measurement and on the quantification of the odour concentration. The research highlights how the results of an dynamic olfactometry analysis can be not only affected by technical and instrumental errors, but also by other individual characteristics of the EN-qualified assessors of the panel. The results of the research can help to improve higher quality performance standard for the dynamic olfactometry analysis, or in generally to taken into consideration the panel composition to calculate the precision and accuracy of the method.

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