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A Monte-Carlo simulation of the measurement uncertainty of olfactometry

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Olfactometric measurements are based on the odour perception by human panels. Due to the variability of the biologic sense of smell, the results of olfactometry show a large amount of scatter. To understand the sources of uncertainty a Monte-Carlo-simulation model has been developed which emulates the olfactometric measurement process in detail. The influence of every parameter, as specified in the European norm EN 13725, is studied and its influence on the overall uncertainty is determined. The simulation results show a measurement uncertainty of 4.5 dB_{OD}, which means an error band between one third and the threefold of an actual measurement value. From round robin tests even a higher uncertainty is reported. The value derived from these tests is 6 dB_{OD}.

1. Introduction

Olfactometry is the standard procedure for the determination of the odour concentration of air samples (Harreveld 1999). In legislation limit values are expressed in this measurand. Unfortunately no indication is given in the corresponding European norm EN 13725 for the measurement uncertainty of the method. In discussions between experts the high amount of uncertainty is conceded, but there is no consensus about the exact level and the way to express the uncertainty in protocols.

A first estimation of the uncertainty may be drawn from the physiological Weber-Fechner law, saying that the smallest perceivable difference between two stimuli is the twofold between the two levels. Under such conditions with factor relations it is much more convenient to express uncertainty in the decibel scale. In the following the measurement uncertainty is given in dB_{OD}, which is defined as 10 * log (olfactometric result / real odour concentration). In the context of the Weber-Fechner law a measurement uncertainty of +-3 dB_{OD} means, that the 95% confidence interval spans from half to double the value, e.g. for a measurement of 1.000 OU/m³ the uncertainty ranges from 500 to 2.000 OU/m³.

The measurement procedure of the EN 13725 involves 4 to 8 panelists for the determination of the odour concentration. Therfore the amount of measurement uncertainty is not obvious, as estimated from the Weber-Fechner law for a single panel member.

In our scientific study we analysed three approaches for the determination of uncertainty.

1. The internal specifications of the EN 13725
2. The results of round robin tests
3. A Monte-Carlo-simulation of the measurement procedure

All calculations are based on the 'Guide to the expression of uncertainty in measurement', abbreviation GUM (GUM 1993).

2. Internal specification of the EN 13725

The uncertainty is not explicitly mentioned in the norm EN 13725. From the limits for the repeatability of measurements in a certain laboratory, the norm requires a standard deviation of 0,1721 in the logarithmic scale. Two times the standard deviation for an intervall including 95% of the values is 0,3442 or expressed as decibel, 3,44 dB_{OD}. This value is not the measurement uncertainty, as it only gives a limit for the random deviations of a laboratory, not saying anything about the systematic deviations, the bias of the laboratory. The real measurement uncertainty therefore must be higher than the value derived from the EN 13725.

3. Uncertainty from round robin tests

In the years 2003 and 2005 round robin tests have been conducted (Maxeiner 2004, 2006). For the calculation of the measurement uncertainty we used:

1. The results from the measurements of the n-butanol certified reference substance
2. Only the results of certified laboratories, working according to the EN 13725

An expanded uncertainty of measurement (95% interval) of 6 dB_{OD} resulted from the calculations. Translated form the decibel-scale to the level of the odour concentration values this uncertainty means a span between one-forth and the fourfold of a measured odour concentration value.
In figure 1 the results as calculated from the round robin tests are displayed. Every result is recalculated as a (virtual) detection threshold for the olfactometric panel. Those in the positive logarithms (higher than 1 OU) are less sensitive than those in the negative ones. The 95.5% limits are at -0.6 and +0.6 respectively. Translated in the threshold values this means 0.25 OU and 4 OU.

4. Monte-Carlo simulation of the olfactometry

In order to understand the sources of uncertainty in olfactometry we decided to set up a Monte-Carlo simulation model (Boeker 2007, Siebert 2004). The aim was to identify the sources of uncertainty with parameter studies on the model. The interpretation of measurements is limited to a given measurement procedure (e.g. 4 panellists and a certain olfactometer) and to the specified criteria of the EN 13725. So the influence of the different influences on the uncertainty can not be distinguished from real measurements. With the model however, it is possible to set each parameter to different levels, exclude certain influences from the procedure and thus to determine the main effect that influence the measurement uncertainty.

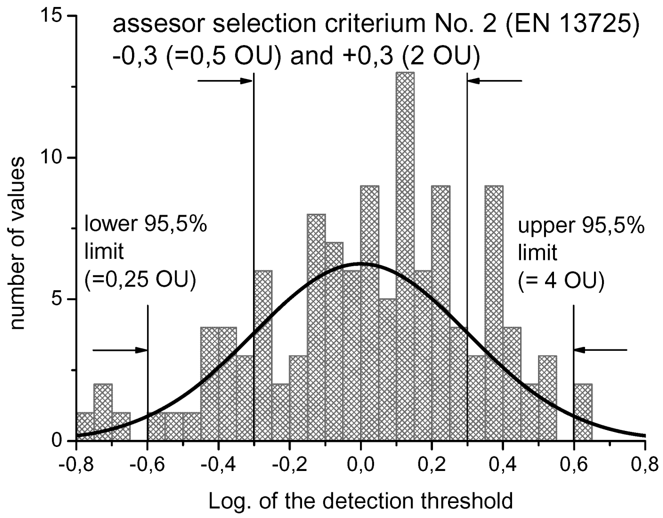

Fig. 1: Result of the round robin tests 2003 and 2005 for the certified reference material n-butanol.

In figure 2 the scheme of the olfactometric measurement is displayed. An odour sample (e.g. 300 OU/m³) is diluted in steps, following a geometric series. At the odour ports the concentration is presented to the panellists. Each panellist had another individual detection limit in a range which is specified in the EN 13725. The panellists give the signal for the odour perception at different dilution steps. The individual threshold is assigned to the geometric mean between the steps. The overall result itself is calculated as the geometric mean of all the results of the panellists.

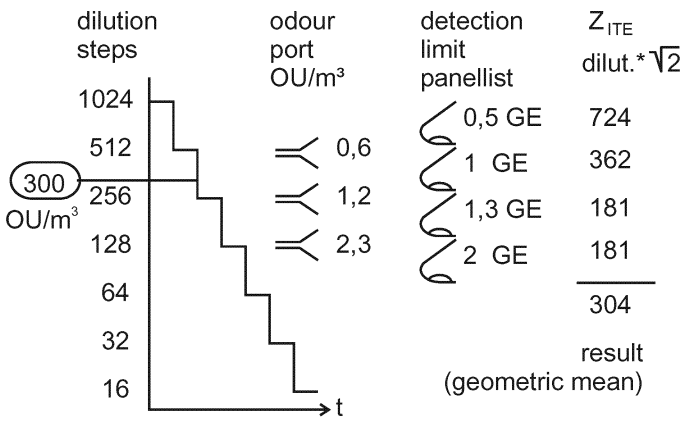

Fig. 2: Scheme of the olfactometry as standardised in the EN 13725.

For the Monte-Carlo simulation every detail was implemented in the model.

1. The odour samples are generated by random choice. The distribution of the samples is uniform on the level of the logarithms.
2. The individual detection limit of the panellists is randomly generated according to the EN 13725. Both criteria of the norm are implemented, the range of the medium values and the standard deviation.
3. The steps of the dilution can be generated in the range between 1.4 and 2.4 as provided by the EN 13725.
4. The error of the dilution system is adjustable.
5. The retrospective classification of the panellists is implemented

It has resulted that the selection of the panel members according to the two criteria of the EN 12725 has the dominant influence on the measurement uncertainty. This derives from the fact that the criterion 1, the standard deviation criterion, leads to a broad distribution of possible individual threshold values. In figure 3 the distribution is given, calculated with a separate model under variation of the standard deviation. With a very small standard deviation the distribution is equal between the boundaries of the mean values (0.5 and 2 OU). With the standard deviation of 0.361728 (=log [2.3]) the distribution becomes very broad, with nearly 23% of the detection limits under and 23% over the limits of 0.5 and 2 OU respectively.

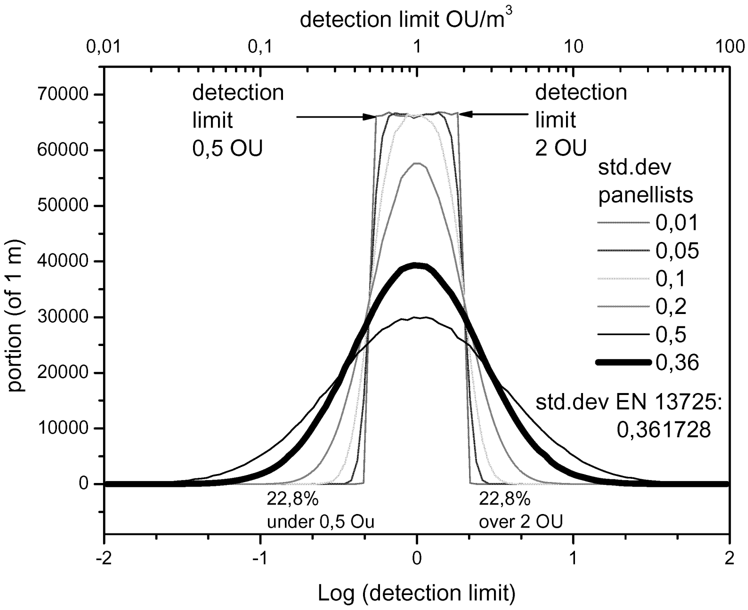

Fig. 3: Distribution of the individual detection thresholds of panel members according to the EN 13725

The detailed results of the different simulation scenarios are shown in figure 4.

1. The variation of the dilution factor between 1.4 and 2.4 between the steps is of minor influence on the measurement uncertainty.
2. The restriction of the mean values of the assessor selection criterion 2 from 0.5-2.0 too much narrower bandwidths also shows a small decrease of the uncertainty. Bearing in mind that this narrow bandwidths are unrealistic to archive in praxis, this is not a means to reduce measurement uncertainty.
3. The reduction of the allowed standard deviation of the individual threshold values of the assessors reduces the uncertainty significantly. As this standard deviation reflects real physiological facts, an arbitrary setting is not possible.
4. The number of panel members is of high influence as expected, but enhances the efforts of olfactometry.
5. An interesting effect came out when studying the effect of the retrospective assessor screening. Instead of reducing the uncertainty, the uncertainty heightened clearly. The reason lies in an unexpected statistical effect under the conditions of the simulation (details in Boeker 2007).

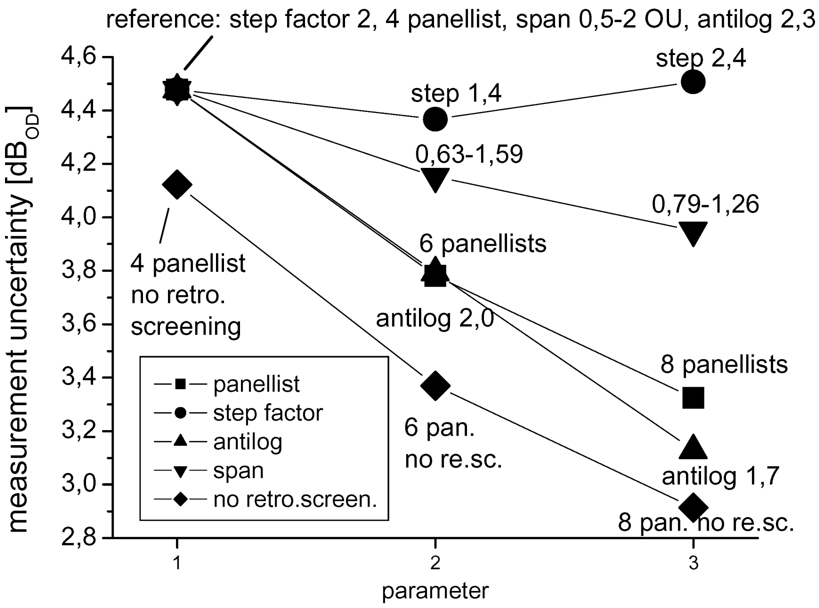

Fig. 4: Results of the Monte-Carlo simulation of olfactometry

5. Outlook

The level and the reasons for the measurement uncertainty of olfactometry have been determined.

The results of the Monte-Carlo-simulation are in accordance with the observed results of international olfactometric round robin tests. The overall measurement uncertainty from the round robin tests of 2003 and 2005 for EN 13725 compliant laboratories is 6 dB_{OD}. This means a 95% uncertainty interval from a quarter to four times of the measured value.

The high amount of uncertainty has influence on conformity statements, e.g. the compliance with set limit values. Another impact of the uncertainty is the methodology of technical odour measurements. The so-called electronic noses need to be calibrated with olfactometric reference measurements. Under the condition of the high uncertainty the referencing procedure has to account for his uncertainty to avoid irregular mathematical methods and over fitting.

6. References

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