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The Synergy of Olfactometry and Sensorial Analysis – Setting a New Standard to Determine Odour Emission Thresholds for BREF Slaughterhouses and Animal By-Products

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Processing meat and animal by-products is often accompanied by the release of unpleasant odour. Within the BREF Slaughterhouses and Animal By-Products Best Available Techniques (BAT) are therefore supplied in order to reduce emissions to air of organic and malodourous compounds originating from slaughter and animal by-product processing activities. To determine the efficiency of these BAT's, BAT-associated emission levels (BAT-AEL's) are defined for odour concentration, TVOC, NH_3 and H_2S. In the first draft of the BREF (May 2005) the BAT-AEL of odour concentration was solely defined by olfactometry. Determining the efficiency on olfactometry alone will often provide a biased result as some emission reduction techniques create their own odorous air that might impede the required BAT-AEL.
To address the missing link, OLFASCAN developed a sensorial analysis technique to determine the odour characteristics of emission reduction techniques. The analysis involves assessing undiluted air samples, taken before and after the emission reduction technique, by a panel consisting out of minimal six calibrated human examiners. The goal of the analysis is to obtain a qualitative odour assessment by scoring air samples based on their odour intensity and unpleasantness and by supplying an odour description.
In combination with olfactometry, the sensorial analysis approach was tested on emission reduction techniques of a rendering facility to showcase the synergy between olfactometry and sensorial analysis in assessing BAT-AEL's. The following four emission reduction techniques were examined: (I) well-performing biofilter, (II) insufficiently performing biofilter, (III) well-performing thermal oxidation and (IV) insufficiently performing thermal oxidation. The obtained results highlighted two important findings: (I) a high odour removal efficiency according to olfactometry is not necessarily an indication of a properly working reduction technique if process odour can still be determined via sensorial analysis and (II) a high odour concentration at the outlet of the emission reduction technique is not necessarily an indication of an insufficient technique if the process odour is completely absent. From these findings, the BAT-AEL for odour concentration was redefined in the final draft of the revised BREF, stating: "*An exception to the BAT-AEL is allowed if, in the case of combustion techniques (BAT-AEL = 1.100 $ou_E.m^{-3}$), the odour abatement efficiency is ≥ 99 % or, as an alternative, process odour is no longer perceptible, or, in case of non-combustion techniques (BAT-AEL = 3.000 $ou_E.m^{-3}$), the odour abatement efficiency is ≥ 92 % or, as an alternative, process odour is no longer perceptible*". The elaboration of a well-defined procedure by OLFASCAN on how to examine odour samples in a qualitative way gives answer to the new rules defined in the revised BREF.

1. Introduction

Meat consumption has become indispensable to our world, resulting in a global annual meat consumption of 350 million tons (Ritchie et al., 2019). The high meat demand is supplied via slaughterhouses but in order to stimulate effective waste management, animal by-products of slaughterhouses need to be processed as well. Processing meat and animal by-products is however accompanied by the release of unpleasant odour which creates a negative odorous impact on the environment (Kreis, 1978; Ubeda et al. 2013). The odorous impact on the environment of slaughterhouses was investigated by Van Broeck et al. (2001) via dose-response relation (odour nuisance versus odour concentration) and showcased a no effect level of only 0.5 $se.m^{-3}$ as 98^{th}

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percentile (sniffing unit (se) is odour concentration determined via sniffing measurements in the field, according to EN 16841-2 (CEN, 2017)). This implies that low concentrations of odour originating from slaughterhouses and process facilities of animal by-products can already create significant odour impact on the environment. Within the BREF Slaughterhouses and Animal By-Products Best Available Techniques (BAT) are therefore supplied in order to reduce odorous emissions originating from the processing activities. To determine the efficiency of these BAT's, a BAT-associated emission level (BAT-AEL's) is defined for odour concentration, but is in the first draft of the BREF (May 2005) restricted to determination by olfactometry. Olfactometry alone can however provide a biased result as some emission reduction techniques create their own odorous air that might impede the required BAT-AEL. Odour emissions are a complex mixture of volatile chemicals and therefore cannot be completely assessed by a stand-alone odour monitoring technique (Muñoz et al., 2010).

To address the complexity of odorous emissions, OLFASCAN developed a sensorial analysis technique to be used as a complementary technique to olfactometry. It allows to determine the odour characteristics of emission reduction techniques in regard to their odour concentrations. The analysis involves assessing undiluted air samples, taken before and after the emission reduction technique, by a panel consisting out of minimal six calibrated human examiners. The examiners fulfil the requirements of odour assessors according to EN 13725 (CEN, 2022). The goal of the analysis is to obtain a qualitative odour assessment by scoring air samples based on their odour intensity and unpleasantness and by supplying an odour description.

This study investigated the synergy between olfactometry and sensorial analysis in assessing BAT-AEL's by combining the olfactometry and sensorial method. For this purpose, the technique was used to study the odour removal efficiency of two emission reduction techniques of a rendering facility under following four scenarios: (I) well-performing biofilter, (II) insufficiently performing biofilter, (III) well-performing thermal oxidation and (IV) insufficiently performing thermal oxidation.

2. Materials and methods

2.1 Experimental setup and sampling procedure

The experiment was setup at a rendering facility. To treat odorous air emissions, the facility has two reduction techniques: (I) thermal oxidation with prior scrubbing to treat non-condensable air emissions and (II) biofiltration with prior water scrubbing to treat air emissions from the unclean unloading hall. The experiments in regard to the biofiltration technique were executed at two different moments to allow for a more deteriorated state of the biofilter material and hence a loss in efficiency reduction (i.e. insufficiently performing biofilter). For the thermal oxidation technique, the experiment was executed at the same day, but once under optimal temperatures of combustion (850 °C – i.e. well performing thermal oxidation) and once under sub-optimal temperatures of combustion (600 °C – i.e. insufficiently performing thermal oxidation). An overview of the executed experiments is listed in Table 1.

Table 1: Description of experimental setup

Experiment ID	Description	Sampling date
ID 1	Well-performing biofilter (optimal material state)	17/11/2020
ID 2	Insufficiently biofilter (deteriorated material state)	27/10/2021
ID 3	Well-performing thermal oxidation (850 °C)	26/10/2017
ID 4	Insufficiently performing thermal oxidation (600 °C)	26/10/2017

To collect the air samples, a Nalophane sampling bag was mounted into an airtight receptacle (barrel), filling the bag with air by creating an under pressure in the receptacle according to the lung principle (Guillot, 2012). In case of the biofilter, a 2 m x 4 m transparent plastic cover was placed over the biofilter surface in order to isolate a fraction of the conveyed air flow (Capelli et al., 2013).

2.2 Olfactometry

The olfactometric analyses were carried out by a certified laboratory. The analysis is carried out in accordance with the European standard EN 13725: 'Determination of odour concentration by dynamic olfactometry' (CEN, 2022).

The sampled air taken for olfactometry is in duplex to address for fluctuations in the process air. The collected air samples are prior diluted and subsequently offered to a panel of selected odour calibrated assessors. The air samples are initially presented to the panel members in such a diluted state that no one can distinguish the odour from odour-free air. The sample dilution is then reduced in consecutive steps (decrement in dilution by maximal a factor 2) so that the odour becomes increasingly stronger. When 50 % of the panel members can distinguish the odour with certainty from odour-free air, there is an odour concentration of one odour unit per m^3

of air ($ou_E.m^{-3}$). The odour concentration of an odour sample is therefore equal to the number of times the sample must be diluted to achieve an odour concentration of 1 $ou_E.m^{-3}$. By definition, one odour unit per cubic meter is equal to the concentration of a compound or mixture of compounds at which 50 % of calibrated observers can just distinguish it from odour-free air. From the obtained odour concentrations of the duplex air samples, the geometric mean is calculated.

2.3 Sensorial analysis

The collected air samples from the different experiments were also subjected to sensorial analysis. This analysis is conducted in an odour-free area and executed by at least six odour calibrated panel members (odour calibration in accordance to EN 13725 (CEN, 2022)). The panel members gently press on the air samples to release the odour and sniff directly from the sample.The purpose of this analysis is to obtain a description of the odour character and to determine two parameters, namely odour intensity and odour (un)pleasantness. The evaluation of these parameters is done using a score (Table 2).

Table 2: Score scaling of odour intensity and odour (un)pleasantness

Odour intensity	Odour (un)pleasantness
Undetectable (0)	Neutral to pleasant (0)
Very weak (1)	Slightly unpleasant (-1)
Weak (2)	Unpleasant (-2)
Clear (3)	Very unpleasant (-3)
Strong (4)	Extremely unpleasant (-4)
Very strong (5)	
Extremely strong (6)	

3. Results and discussion

3.1 Biofiltration

Table 2 gives an overview of the results of olfactometry in combination with odour description based on sensorial analysis of the air samples collected before the water scrubbing (i.e. untreated air – IN) and after biofiltration (i.e. treated air – OUT) and this for the optimal and deteriorated state of the biofilter (experiment ID 1 and ID 2).

Table 2: Olfactometry results and odour description of biofilter experiment

Experiment ID	Sampling point	Concentration ($ou_E.m^{-3}$)	Efficiency (%)	Description
ID 1	IN	26822	-	offal, rotten, rendering
	OUT	1232	95,4	soil, bark/wood, compost
ID 2	IN	299680	-	rotten, offal, rendering
	OUT	9377	96,9	woody, soil, sulphur smell

Figure 2 illustrates how the odour was scored in accordance to its odour intensity and odour (un)pleasantness.

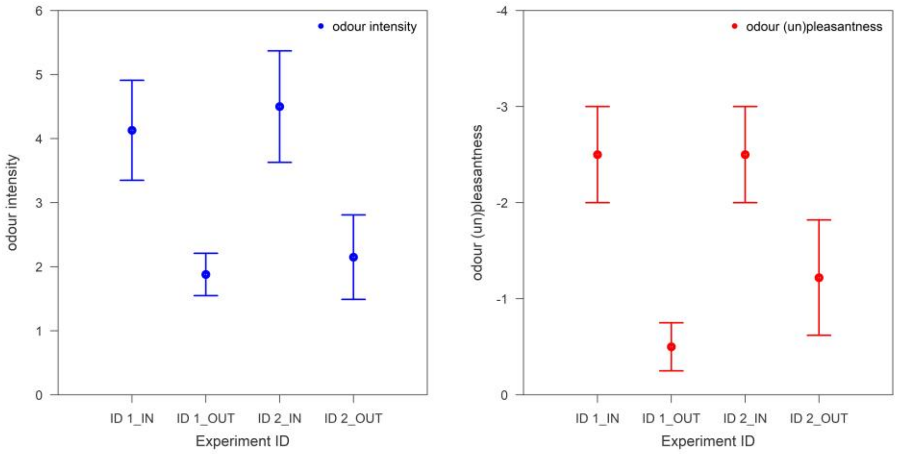

Figure 2: Sensorial analysis results of the biofilter experiment

The results indicate that the well-performing biofilter resulted in an odour concentration of approximately 1.000 $ou_E.m^{-3}$ and more importantly in an odour description wherein process odour was no longer present. The residual smell was scored as mainly neutral. For the insufficiently performing biofilter, the residual odour concentration was approximately 9.000 $ou_E.m^{-3}$ and with a presence of untreated sulphur smell in the odour description. As a result, the residual smell was scored as mainly slightly unpleasant.
Focusing on the removal efficiency, both the well and insufficiently performing biofilter (optimal material state vs deteriorated material state) attained a similar high removal efficiency. An important side note is that the untreated odour concentration of experiment ID 2 was 10 times higher than of experiment ID 1. The unclean unloading hall contained four times more carcasses during experiment ID 2 than ID 1, explaining the much higher odour concentration that needed to be treated.
Nonetheless, the removal efficiency would indicate in both cases a well performing biofilter. By incorporating the results of the sensorial analysis it became clear that untreated process air was partially being emitted from the biofilter, thus hinting to an insufficient odour reduction.

3.2 Thermal oxidation

Table 3 gives an overview of the results of olfactometry in combination with odour description based on sensorial analysis of the air samples collected before scrubbing (i.e. untreated air – IN) and after thermal oxidation (i.e. treated air – OUT) and this for the optimal and sub-optimal combustion temperatures (experiment ID 3 and ID 4).

Table 3: Olfactometry results and odour description of thermal oxidation experiment

Experiment ID	Sampling point	Concentration ($ou_E.m^{-3}$)	Efficiency (%)	Description
ID 3	IN	999231	-	offal, rotten, non-condensable fumes (NCF)
	OUT	1294	99,9	gas, prickling
ID 4	IN	999231	-	offal, rotten, NCF
	OUT	54741	97,5	rendering, NCF, gas

Figure 3 illustrates how the odour was scored in accordance to its odour intensity and odour (un)pleasantness.

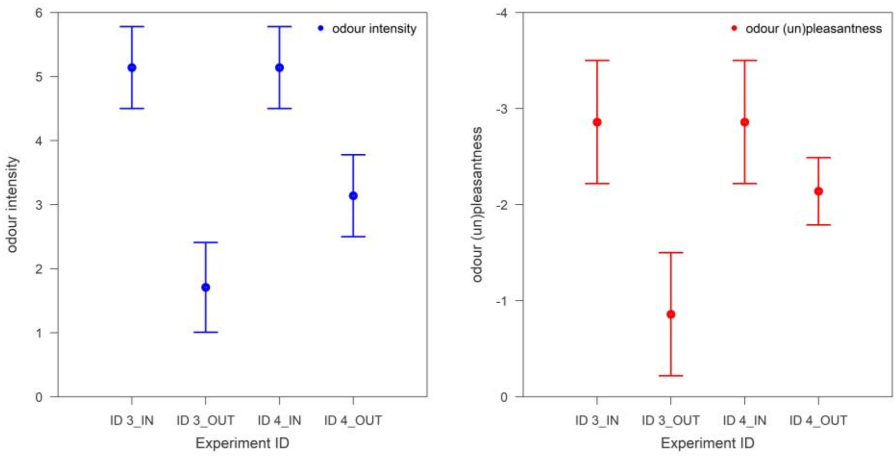

Figure 3: Sensorial analysis results of the thermal oxidation experiment

Similar to the results of the biofilter, the olfactometry hints towards a well-performing thermal oxidation, both under optimal and suboptimal combustions temperatures, as a high removal efficiency was achieved in both cases. However, the residual odour concentration of thermal oxidation under sub-optimal combustion temperatures was around 40 times higher than under optimal combustion temperatures, and more importantly, in case of sub-optimal combustion untreated process air (rendering, non-condensable gases) was still detectable according to the sensorial analysis. As a result, the residual smell of thermal oxidation under suboptimal combustion temperatures was scored as mainly unpleasant.
By combining olfactometry with sensorial analysis it became clear that (I) a high odour removal efficiency according to olfactometry is not necessarily an indication of a properly working reduction technique if process odour can still be determined via sensorial analysis and (II) a high odour concentration at the outlet of the

emission reduction technique is not necessarily an indication of an insufficient technique if the process odour is completely absent.

3.3 BAT-AEL standard

Through the course of several years OLFASCAN utilised the found synergy between olfactometry and sensorial analysis to collect emission reduction data from rendering facilities. To determine the efficiency of the odour emission reduction technique, the following parameters were investigated: (I) odour concentration at outlet, (II) odour concentration removal efficiency and (III) presence of untreated process air at outlet. The outcome of these three parameters determined whether the emission reduction technique is working properly or not. An overview of the data and the evaluation is listed in Table 4.

Table 4: Data overview and evaluation emission reduction technique

Technique	Sampling date	Concentration at outlet ($ou_E.m^{-3}$)	Efficiency (%)	Process odour (present/absent)	Evaluation (OK/NOK)
Biofilter	5/07/2017	2452	92,7	present	NOK
Biofilter	5/07/2017	379	98,1	absent	OK
Biofilter	5/07/2017	303	99	absent	OK
Biofilter	5/07/2017	1128	99,1	present	NOK
Biofilter	5/07/2017	1239	99	absent	OK
Biofilter	28/06/2018	130	98,7	absent	OK
Biofilter	28/06/2018	166	95,6	absent	OK
Biofilter	28/06/2018	212	93,3	absent	OK
Biofilter	28/06/2018	5479	91,1	present	NOK
Biofilter	28/06/2018	634	99,7	absent	OK
Biofilter	27/06/2019	364	99,7	absent	OK
Biofilter	27/06/2019	63	98,9	absent	OK
Biofilter	27/06/2019	40	99,1	absent	OK
Biofilter	27/06/2019	7721	88,7	present	NOK
Biofilter	27/06/2019	304	99,7	absent	OK
Biofilter	12/03/2020	116	99,8	absent	OK
Biofilter	12/03/2020	1031	98,3	absent	OK
Biofilter	12/03/2020	324	94,2	absent	OK
Biofilter	12/03/2020	339	96,3	absent	OK
Biofilter	27/10/2021	133	99,5	absent	OK
Biofilter	27/10/2021	167	99,1	absent	OK
Biofilter	27/10/2021	3101	98,6	present	NOK
Biofilter	27/10/2021	4634	97,6	present	NOK
Biofilter	8/06/2022	2810	97,7	present	NOK
Biofilter	8/06/2022	119	96,2	absent	OK
Biofilter	8/06/2022	165	97,7	absent	OK
Biofilter	19/10/2022	112	99,8	absent	OK
Biofilter	19/10/2022	180	99,7	absent	OK
Thermal oxidation	5/03/2013	2988	99,9	absent	OK
Thermal oxidation	5/03/2013	2392	99,9	absent	OK
Thermal oxidation	16/05/2013	1490	99,9	absent	OK
Thermal oxidation	16/05/2013	2843	99,9	absent	OK
Thermal oxidation	16/05/2013	3040	99,9	absent	OK

From these results, and from results obtained from other rendering facilities and slaughterhouses, the BAT-AEL standard for odour concentration was redefined in the final draft of the revised BREF Slaughterhouses and Animal By-Products (Karlis et al., 2024), stating: "*An exception to the BAT-AEL is allowed if, in the case of combustion techniques (BAT-AEL = 1.100* $ou_E.m^{-3}$*), the odour abatement efficiency is ≥ 99 % or, as an alternative, process odour is no longer perceptible, or, in case of non-combustion techniques (BAT-AEL = 3.000* $ou_E.m^{-3}$*), the odour abatement efficiency is ≥ 92 % or, as an alternative, process odour is no longer perceptible*".

4. Conclusions

Through years of investigating odour emission reduction techniques at rendering facilities and slaughterhouses by combining olfactometry with sensorial analysis, it became clear that olfactometry as stand-alone analysis often lacks the required potential to correctly determine the odour removal efficiency of the technique. Odour emissions are a complex mixture of volatile chemicals so naturally a combination of odour monitoring techniques is required to allow a more complete assessment. The sensorial analysis technique allows to determine whether untreated process odour is still present after the odour reduction technique, while the intensity and unpleasantness scaling translates to how the odour will be perceived by the surroundings. This type of information is crucial for rendering facilities and slaughterhouses as minimizing odour impact to the environment is pivotal to their environmental permit.

The found synergy between olfactometry and sensorial analysis highlighted the important finding that (I) a high odour removal efficiency according to olfactometry is not necessarily an indication of a properly working reduction technique if process odour can still be determined via sensorial analysis and (II) a high odour concentration at the outlet of the emission reduction technique is not necessarily an indication of an insufficient technique if the process odour is completely absent. From these results, the BAT-AEL standards in the revised BREF Slaughterhouses and Animal By-Products were adjusted to reflect the added value of combining olfactometry with sensorial analysis. The elaboration of a well-defined procedure by OLFASCAN on how to examine odour samples in a qualitative way gives answer to the new rules defined in the revised BREF.

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