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Odour emission factors for assessment and prediction of Italian rendering plants odour impact

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Abstract

Among the industrial activities that may cause odour nuisance problems, rendering plants represent one of the most critical sources of smelly gaseous emissions and consequently of odour complaint. In this work, the odour emission factors (OEFs) for the rendering industry are determined based on experimental data obtained by means of dynamic olfactometry. An OEF is a representative value that relates the quantity of odour released to the atmosphere to a given associated activity. The odour emission factors were calculated to be equal to 4.52×10^8 $\mathrm{ou_E\,t^{-1}}$ for process air, to 8.02×10^7 $\mathrm{ou_E\,t^{-1}}$ for a mixture of process air and ambient air, and to 3.53×10^3 $\mathrm{ou_E\,t^{-1}}$ for wastewater treatment tanks. Furthermore, the efficiencies of different odour abatement systems used for the treatment of different gaseous emissions from this kind of facility are evaluated and compared. The abatement efficiencies of the monitored odour reduction systems decrease passing from combustors (efficiencies over 99%) to biofilters (efficiencies between 73 and 80%) and scrubbers (efficiencies between 41 and 60%).

Keywords: Rendering process; Odour emissions; Dynamic olfactometry; Odour emission rate

1. Introduction

Meat rendering plants process animal by-product materials for the production of tallow, grease, and high-protein meat and bone meal. The rendering process comprises a number of processing stages, although the order may vary between installations. Preparing the raw material for rendering generally involves size reduction. The material is then heated under pressure to kill micro-organisms and to remove moisture. The liquefied fat and the solid protein are separated by centrifugation and/or pressing, whereas the solid product may then be ground into a powder. The final products are transferred to storage and dispatch, and the waste solids, liquids and gases are then treated and disposed of [1].

One important aspect of the rendering process is the quick deterioration that takes place immediately after slaughtering, which progresses more and more rapidly up to the treatment at the rendering plants. The volatile compounds that are produced during the enzymatic decomposition and the oxidation of proteins cause are responsible for the penetrating odour that can be perceived during the manipulation and transformation of animal scraps. These polluting products can be found as punctual emissions from the stacks that emit the fumes coming from the transformation processes into the atmosphere, and as diffuse emissions in the working environment caused by the presence of vapours leaks from machinery and by the biological degradation of stocked raw and semiprocessed materials. The biological depuration of the wastewaters, that are generated by the condensation of the cooking fumes and from the washing of the working ambient, causes the production of diffuse unpleasant odour emissions as well. In particular, the odorous compounds that have been identified in gaseous emissions from rendering plants include hydrogen sulfide (H_2S), ammonia (NH_3), organic sulfides, disulfides, mercaptans (methanethiol), aldehydes (especially C-4 to C-7 aldehydes), amines (trimethylamine, C-4 amines), quinoline, dimethyl pyrazine, other pyrazines, indole, skatole and C-3 to C-6 organic acids. In addition, lesser amounts of C-4 to C-7 alcohols, ketones, aliphatic

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hydrocarbons, and aromatic compounds are potentially emitted [2–4].

For the above mentioned reasons, one of the most important characteristics associated with the rendering process is the emission of volatile compounds and of unpleasant odours that often cause nuisance to the people living near the plants [5,6], and that make the rendering industry one of the industrial sectors with the greatest problems of odour impact [1].

The applicability of quantitative limits to the entity of annoying odour emissions for the safe protection of people's health and well-being, is bound to the technical possibility of making the measurement method repetitive and objective. An objective odour concentration measurement can be obtained by means of a sensorial technique called dynamic olfactometry [7], which enables to quantify odour concentration in European odour units per cubic meter ($\mathrm{ou_E\,m^{-3}}$) [8].

The results of olfactometric measurements relevant to specific sources can be used for the calculation of odour emission factors (OEFs) for different processes or production technologies. In analogy to material emission factors [9], OEFs are defined as the characteristic values that relate the emitted odour quantity with an activity index associated with the release of such odour. In the estimation of OEFs for industrial plants, these values can be calculated as the product of the emitted odour concentration ($\mathrm{ou_E\,m^{-3}}$) by the emitted air flow ($\mathrm{m^3\,s^{-1}}$), divided by a specific index, which may be for example the gross weight production, the site surface or a time unit [10].

OEFs represent a useful tool for the predictive estimation of a rendering plant odour impact, as they can be used as input data for the application of specific odour dispersion models [11,12]. It must be taken into account that OEFs used for the calculation of a plant odour impact should be corrected with a factor that takes account of the average abatement efficiency of the adopted odour abatement systems.

Data regarding the chemical concentration of pollutants, resulting from measurement campaigns on representative sources, are generally available as a function of the processing type and/or the fume depuration technology. On the contrary, the data that can be found in literature concerning odour concentrations and odour flow rates are few and with poor reliability. This fact represents a serious limit for the availability of "bibliographical" OEFs and require that OEFs are created by starting from experimental laboratory data.

2. Experimental

2.1. Collection of odour concentration data

In order to determine OEFs for the rendering industry, the data regarding 14 different rendering plants were collected. In some of the plants being monitored for this study, the samplings were carried out in different seasons and with different weather conditions, in order to have a significant number of representative samples for all the odour sources present on each plant. Air samples were taken upstream and downstream of different odour abatement systems that treat the air collected from the process or from the manufacturing departments. The air coming from the cooking, boiling and pressing operations, which is characterised by an intense odour charge, is defined as "process air". "Department air" is the air coming from the department aeration systems and from free manufacturing areas, which is generally less odorous. Furthermore, air samples were collected on the tanks for the treatment of wastewater coming from the rendering operations (oxidation, secondary sedimentation, anaerobic digestion and sludge settling tanks). These samples were collected from the plants provided with a wastewater treatment plant inside the rendering facility.

2.2. Sampling

The collection of air samples conformed with the requirements of EN 13725:2003, using Nalophan™ bags equipped with a Teflon™ inlet tube.

Sampling on area sources (i.e. wastewater treatment tanks) was carried out using a wind tunnel system [13], which consists of a PET hood that is positioned over the emitting surface. A neutral air stream, filtered through activated carbon, is introduced at a known velocity by a fan, simulating the wind action on the liquid surface. Air samples are then collected in the outlet duct by means of a vacuum pump. Mass transfer from the monitored surface to the gaseous phase is guaranteed by the air stream velocity (convective mass transfer) [14,15]. This phenomenon can be described according to the Prandtl boundary layer theory, and the mass transfer coefficient calculated using the following expression:

$$K_\mathrm{c} = \frac{0.664D}{l} Re^{1/2} Sc^{1/3} \tag{1}$$

where K_c is the mass transfer coefficient ($\mathrm{m\,s^{-1}}$), D the molecular diffusivity of the odorous compounds in the liquid phase and l is the length of the contact area between gaseous phase and liquid phase in the air flow direction, i.e. the length of the wind tunnel base and Re is the Reynolds number and Sc the Schmidt number [16].

The wind tunnel (Fig. 1) used during the experimentation has a circular section inlet and outlet duct, of 0.08 m diameter. The central body of the hood used was a 0.25 m wide, 0.08 m high and 0.5 m deep rectangular section chamber. Inside the inlet duct there is a perforated stainless steel grid and inside the divergent that connects this duct to the central body of the hood there are three flow deflection vanes. Both these devices have the function of making the airflow as homogeneous as possible [17].

2.3. Analysis

Olfactometric analyses were conducted in conformity with EN 13725 (2003).

An olfactometer Mannebeck model TO7, based on the "yes/no" method, was used as a dilution device. This instrument with aluminium casing has four panellists' places in separate open boxes. Each box is equipped with a stainless steel sniffing port and a push-button for "yes" (odour threshold). The measuring range of the TO7 olfactometer starts from a maximum dilution factor of 1/64,000 with a dilution step factor of 2. All

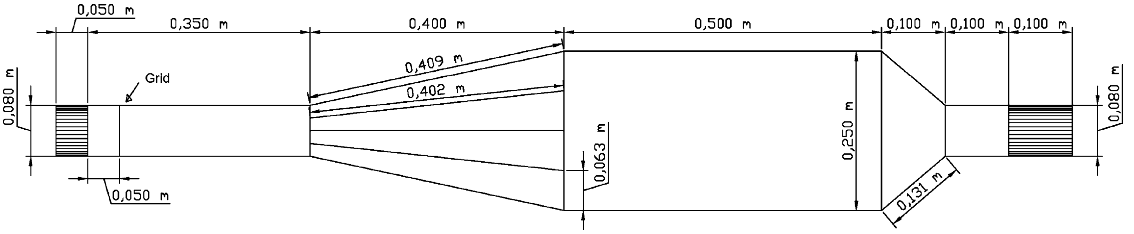

Fig. 1. Plant of the wind tunnel.

measurements were carried out within 30 h after sampling, relying on a panel composed of eight panellists (4 + 4), adequately selected in conformity with EN 13725:2003.

The odour concentration was calculated as the geometric mean of the odour threshold values of each panellist, multiplied by $\sqrt{2}$.

2.4. Calculation of OEFs

Once the air samples were collected in the inlet duct of the abatement systems and their odour concentration was measured, it was possible to determine the Odour Emission Rate (OER) associated with each emission. The OER ($\text{ou}_\text{E}\ \text{s}^{-1}$) is calculated as the product of the odour concentration ($\text{ou}_\text{E}\ \text{m}^{-3}$) and the air flow ($\text{m}^3\ \text{s}^{-1}$) conveyed to the odour abatement system. For the case of area sources, the determination of the OER requires the calculation of a parameter called Specific Odour Emission Rate (SOER), which is expressed in $\text{ou}_\text{E}\ \text{s}^{-1}\ \text{m}^{-2}$ and can be obtained by multiplying the odour concentration measured at the outlet of the wind tunnel ($\text{ou}_\text{E}\ \text{m}^{-3}$) with the flow rate of the inlet air ($\text{m}^3\ \text{s}^{-1}$) and dividing by the base area of the central body of the hood (m^2) [18]. The OER is then calculated as the product of the SOER and the emitting surface (m^2) of the considered area source.

The optimum air velocity inside the central body of the hood is about $0.3\ \text{m}\ \text{s}^{-1}$ [14,18], which corresponds in this case to an inlet air velocity of $1.2\ \text{m}\ \text{s}^{-1}$. During field measurements it was not always possible to achieve exactly the desired air velocity. For these reasons SOER values were calculated considering the air velocity measured in the outlet duct of the hood corresponding to each sample collection. Subsequently, the SOER value for each sample was normalized using the following equation [18,19]:

$$\text{SOER}_{v_2} = \text{SOER}_{v_1}\left(\frac{v_2}{v_1}\right)^{1/2} \tag{2}$$

In order to calculate an OEF, the OER must be divided by a specific activity index, which should be representative of the examined plant and associated with emitted odour quantity. In rendering plants, odour emissions can be influenced by different factors, such as for example plant dimensions, or quality and quantity of the animal by-products that are conferred to the plant. Because of the predictive and non-descriptive character of an emission factor (description of plant emissions should be based on more specific data), it is useful to express the emission factor as a function of one possible "rough" aspect of the considered plant. In this case the OEF was related to the plant capacity. This choice is justified by the existence of some documented proportionality between plant capacity and odour emissions. The OEFs calculated in this study are therefore expressed in $\text{ou}_\text{E}\ \text{t}^{-1}$, and express the quantity of odour emitted for each tonne of processed material. As the air suction mode varies with the plant being considered, the odour emission factors were expressed distinctly for "process air", for the mixture of "process air" and "department air", and for the wastewater treatment tanks.

For each emission typology under consideration, the efficiencies of different odour abatement devices, that are largely used in the Italian rendering plants, were evaluated and compared. This comparison was carried out by taking into account the typology of treated air, in order to identify the best abatement system for the reduction of odour impact from rendering plants.

3. Results and discussion

3.1. OEFs relevant to "process air"

The experimental data resulting from the olfactometric measurements carried out on the process air of the examined plants are reported in Table 1. These data were used for the calculation of the average OEFs (Fig. 2) relevant to those plants

Table 1
Odour concentration values relevant to "process air"

Plant	Campaign	Capacity $(\text{t}\ \text{y}^{-1}) \times 10^3$	Air flow rate $(\text{m}^3\ \text{h}^{-1}) \times 10^3$	Odour concentration $(\text{ou}_\text{E}\ \text{m}^{-3}) \times 10^3$
1	a	30	8	340
	b	30	8	420
2	a	13	25	40
	b	13	25	32
	c	13	25	21
3	a	100	15.2	280
	b	100	15.2	660
	c	100	15.2	460
4	a	216	10	320
	b	216	10	420
	c	216	10	400
5	a	150	13.8	530
	b	150	13.8	600
	c	150	13.8	570
6	a	25	8	160
	b	25	8	180
	c	25	8	160

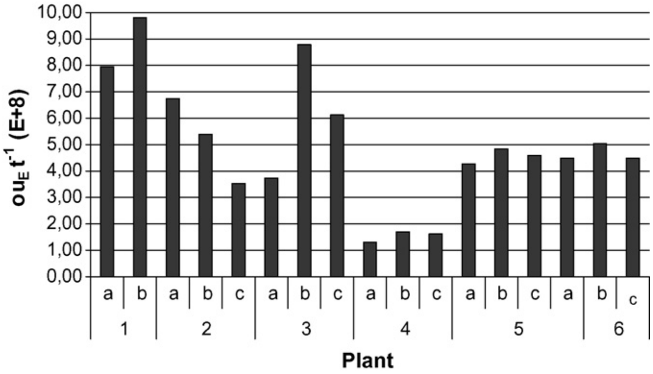

Fig. 2. OEFs relevant to “process air”.

that convey the process air in order to treat it separately (i.e. plants 1–6). The average OEF, obtained as geometric mean of the mean OEF values relevant to the process air in each plant, is 4.52×10^8 $\mathrm{ou_E\,t^{-1}}$. The standard deviation associated with this value is equal to 2.32×10^8 $\mathrm{ou_E\,t^{-1}}$ and the median is equal to 4.59×10^8 $\mathrm{ou_E\,t^{-1}}$.

The odour concentration values (indicated as c_{od}) measured at the inlet and outlet of odour abatement systems that are adopted in the monitored rendering plants for the treatment of the “process air” were used for the calculation of the odour abatement efficiencies (OAEff) of the different abatement systems (Table 2), according to the following equation:

$$\mathrm{OAEff} = \frac{c_{\mathrm{od}}\mathrm{IN} - c_{\mathrm{od}}\mathrm{OUT}}{c_{\mathrm{od}}\mathrm{IN}} \tag{3}$$

The calculated average odour abatement efficiencies of the different abatement technologies being considered are therefore:

$\mathrm{OAEff}_{\mathrm{Combustion}}$: 99.1% (S.D. = 0.13);
$\mathrm{OAEff}_{\mathrm{Biofiltration}}$: 79.8% (S.D. = 1.3);
$\mathrm{OAEff}_{\mathrm{Wet\ absorption}}$: 60.2% (S.D. = 23.5).

Table 2
Odour concentration values at the inlet and outlet of odour abatement systems and per cent abatement efficiency

Odour abatement system	c_{od} IN ($\mathrm{ou_E\,m^3}$) × 10^3	c_{od} OUT ($\mathrm{ou_E/m^3}$) × 10^3	Odour abatement efficiency
Combustor	340	2.2	99.4
Combustor	420	3.5	99.2
Combustor	320	2.2	99.3
Combustor	420	4.5	98.9
Combustor	400	3.5	99.1
Combustor	530	5	99.1
Combustor	600	5.5	99.1
Combustor	570	5.2	99.1
Biofilter	160	35	78.1
Biofilter	180	36	80.0
Biofilter	160	30	81.3
Scrubber	40	13	67.5
Scrubber	32	17	46.9
Scrubber	21	16	23.8
Scrubber	280	36	87.1
Scrubber	660	90	86.4
Scrubber	460	73	84.1

Table 3
Odour concentration values relevant to the mixture of “process air” and “department air”

Plant	Campaign	Capacity ($\mathrm{t\,y^{-1}}$) × 10^3	Air flow rate ($\mathrm{m^3\,h^{-1}}$) × 10^3	Odour concentration ($\mathrm{ou_E\,m^{-3}}$) × 10^3
7	a	30	10	36
	b	30	10	19
8	a	25	20	9
	b	25	20	9.3
	c	25	40	8.3
	d	25	50	6
	e	25	60	3
9	a	22	16	32
	b	22	16	36
	c	22	16	34
10	a	26	13.5	34
	b	26	13.5	32
	c	26	13.5	28
11	a	80	14.6	30
	b	80	14.6	32
	c	80	14.6	33
12	a	10	19	15
	b	10	20	10
	c	10	20	17
13	a	216	10	45
	b	216	10	30
	c	216	10	25
14	a	150	46.8	54
	b	150	46.8	50

3.2. OEFs relevant to mixture of “process air” and “department air”

Although “process air” represents the emission of a rendering plant that most likely can produce olfactory nuisance in the near living population, this type of emission is not always correctly conveyed to an air treatment or odour abatement system. Table 3 shows the odour concentration values relevant to those plant in which the fumes produced from the meat processing machines (defined as “process air”) are not drawn through a dedicated suction system, but they are mixed with the air collected from the processing departments. In these cases the department air, which contains also the process fumes, is sucked and conveyed to the abatement systems.

The odour concentration values were used for the calculation of the average OEF, that can be obtained as geometric mean of the mean OEF values relevant to the mixture of “process air” and “department air” in each plant (Fig. 3). The average OEF is equal to 8.02×10^7 $\mathrm{ou_E\,t^{-1}}$. The standard deviation associated with this value is equal to 7.78×10^7 $\mathrm{ou_E\,t^{-1}}$ and the median is equal to 11.0×10^7 $\mathrm{ou_E\,t^{-1}}$.

The odour concentration values measured at the inlet and outlet of the odour abatement systems adopted for the treatment of the mixture of “process air” and “department air” were used in order to calculate their abatement efficiency (Table 4).

The average odour abatement efficiencies (OAEff) that were calculated for the considered abatement systems are:

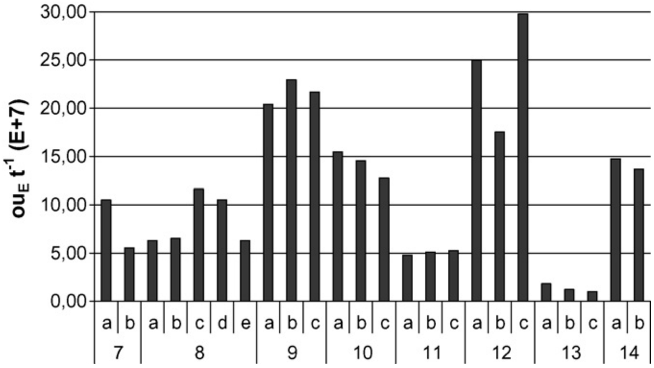

Fig. 3. OEFs relevant to the mixture of “process air” and “department air”.

$\mathrm{OAEff}_{\mathrm{Biofiltration}}$: 73.0% (S.D. = 8.4);
$\mathrm{OAEff}_{\mathrm{Wet\ absorption}}$: 41.1% (S.D. = 18.5).

In this case, the abatement efficiency values are lower than those that were observed for the treatment of the “process air”. These differences are due to the fact that, in general, the efficiency of odour abatement systems raises for increasing values of inlet odour concentration values.

Due to the high operational costs, combustion is generally not used for the treatment of this kind of emission, which presents a significantly lower odour load with respect to the “process air”.

3.3. OEFs relevant to wastewater treatment tanks

Some rendering plants are provided with a plant for the treatment of the wastewaters formed by the process fumes condensation and the washing waters. The wastewater treatment tanks may represent a further source of odour nuisance, especially because the gaseous emissions of these tanks are not treated using appropriate environmental devices but they are released directly into the atmosphere by means of convective phenomena generated by the wind or because of the existence of a temperature gradient between wastewater and atmospheric air.

Table 4
Odour concentration values at the inlet and outlet of odour abatement systems and percent abatement efficiency

Odour abatement system	c_{od} IN $(\mathrm{ou_E/m^{-3}}) \times 10^3$	c_{od} OUT $(\mathrm{ou_E/m^{-3}}) \times 10^3$	Odour abatement efficiency
Scrubber	36	24	33.3
Scrubber	19	9.2	51.6
Scrubber	9	3	66.7
Scrubber	9.3	4.3	53.8
Scrubber	8.3	5.2	37.3
Scrubber	6	2.5	58.3
Scrubber	3	1.5	50.0
Scrubber	15	5	66.7
Scrubber	10	3.2	68.0
Scrubber	17	5.7	66.5
Scrubber	45	40	11.1
Scrubber	30	25.6	14.7
Scrubber	25	20	20.0
Scrubber	54	27	50.0
Scrubber	50	25.6	48.8
Biofilter	32	5.5	82.8
Biofilter	36	6.7	81.4
Biofilter	34	6	82.4
Biofilter	34	10.2	70.0
Biofilter	32	7	78.1
Biofilter	28	6.5	76.8
Biofilter	30	12	60.0
Biofilter	32	12.5	60.9
Biofilter	33	10.2	69.1

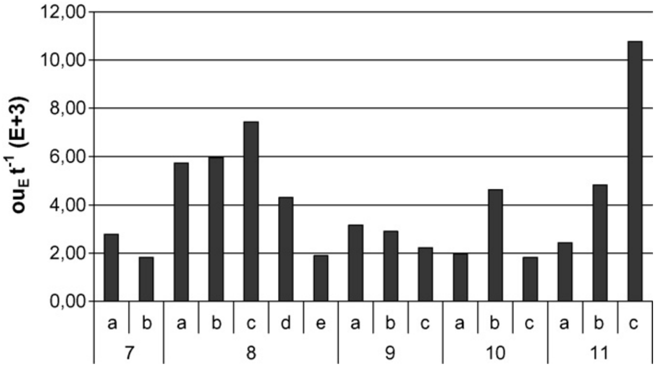

Fig. 4. OEFs relevant to wastewater treatment tanks.

Table 5 reports the results of the odour concentrations measurements that were carried out on the wastewater treatment tanks. These values are the geometric average of the odour concentration values that were obtained by collecting the air samples on different specific portions of the same wastewater treatment tank.

The measured odour concentration values were used for the calculation of the OEFs (Fig. 4), associated with the wastewater and sludge treatment tanks. In analogy with the previously discussed cases, OEFs relevant to the wastewater treatment tanks were referred to the plant capacity, in terms of tonnes of annually raw material being processed. The emissions from wastewater treatment tanks weren’t expressed referring to wastewater amount, in order to make these OEFs comparable with the OEFs relevant to “process air” and to the mixture of “process air” and “department air”. This procedure is justified by the fact that a proportionality between the OER values related to the wastewater treatment tanks and the plant capacity was observed on the monitored plants. The average OEF was obtained as geometric mean of the mean OEF values relevant to the wastewater treatment tanks, and it was calculated to be equal to $3.53 \times 10^3\ \mathrm{ou_E\ t^{-1}}$. The standard deviation associated with this value is equal to $2.40 \times 10^3\ \mathrm{ou_E\ t^{-1}}$ and the median is equal to $3.04 \times 10^3\ \mathrm{ou_E\ t^{-1}}$.

3.4. Odour reduction efficiency

Considering the efficiency evaluation of the examined odour abatement systems, it is possible to observe that combustors represent the most effective system for the reduction of odour from rendering plants. Nonetheless, it must be taken into account that combustion is the most expensive odour abatement technology among the ones considered in this study. The choice of the odour reduction system to be adopted strongly depends on the relation

Table 5
Odour concentration values relevant to wastewater treatment tanks

Plant	Campaign	Capacity ($t\,y^{-1}$) × 10^3	Tank surface (m^2)	Air flow rate ($m^3\,h^{-1}$) × 10^3	Odour concentration ($ou_E\,m^{-3}$) × 10^3
1	a	30	100	1.005	264
	b	30	37	1.005	173
2	a	13	28	1.005	235
	b	13	28	1.005	244
	c	13	84	1.005	305
3	a	25	50	1.005	340
	b	25	50	1.005	150
	c	25	45	1.005	250
4	a	22	134	1.005	202
	b	22	17	1.005	154
	c	22	15	1.005	137
5	a	26	40	1.005	380
	b	26	45	1.005	150
	c	26	35	1.005	200
8	a	10	45	1.005	152
	b	10	50	1.005	340

between costs and benefits, for this reason, combustion may turn out to be a suitable solution only for big plants. As far as concerns the use of biofilters, their efficiency is relatively high, but this abatement system is not adequate for the reduction of emissions with very high odour concentrations, as those produced by a rendering plant, particularly if the plant is located in an urban context. Finally, the efficiency values relevant to scrubbers are very different one from each other. In general, these differences do not necessarily indicate that scrubbers are not suitable for the reduction of odours in rendering plants. Very low efficiency values mostly depend on the fact that the absorption liquid is not changed frequently enough. In fact, on the monitored plants it was observed that the abatement efficiency of scrubbers can be raised by frequently changing the absorption liquid (scrubbers working with fresh water can reach odour reduction efficiencies of over 80%), rather than by adding specific reactants to water.

4. Conclusions

The OEF values relevant to “process air” (about $10^8\,ou_E\,t^{-1}$) are about 1 order of magnitude greater than the OEFs associated with the mixture of “department air” and “process air” (about $10^7\,ou_E\,t^{-1}$), and about 5 orders of magnitude greater than the OEFs relevant to the odorous air rising from the depuration tanks (about $10^3\,ou_E\,t^{-1}$). Even though the calculated values present considerable differences, the relevance of the obtained OEFs demonstrates that none of the three emission typologies may be ignored in the odour impact determination of a rendering plant. This consideration is so much true when combustion (efficiency > 99%) is applied for the odour concentration reduction of the “process air”. In fact, in this case, the relative contribution of “process air” to the plant total odour impact is reduced by almost 2 orders of magnitude, and becomes therefore comparable with the contributions due to the mixture of “department air” and “process air” and to the wastewater treatment tanks.

The OEFs that were determined in this study can be very useful, as they can be used as emission data for the application of specific odour dispersion models, which enable the prediction and the estimation of the odour impact of a rendering plant. This kind of estimation is very important in order to evaluate the possibility of building a new rendering plant or of expanding an already existing plant, without causing an unacceptable odour annoyance to the near living population.

The precision of the OEFs can be improved and the margin of error reduced by substituting some of the simplifying assumptions that were adopted by the real conditions that are observed on each plant. Moreover, the OEFs may be further “refined” by evaluating their dependence from other parameters that were not considered in this study, such as, for example temperature or humidity.

References

[1] Integrated Pollution and Control (IPPC), Reference Document on Best Available Techniques in the Slaughterhouses and Animal By-products Industries, Institute for Prospective Technological Studies, Seville, 2003.

[2] Z. Shareefdeen, B. Herner, D. Webb, L. Verhaeghe, S. Wilson, An odor predictive model for rendering applications, Chem. Eng. J. 113 (2005) 215–220.

[3] J.R. Kastner, K.C. Das, Wet scrubber analysis of volatile organic compound removal in the rendering industry, J. Air Waste Manage. Assoc. 52 (2002) 459–469.

[4] US Environment Protection Agency (US EPA), Compilation of Air Pollutant Emission Factors, AP 42, vol. I, fifth ed., Food and Agricultural Industries, Research Triangle Park, NC, 1995 (Chapter 9).

[5] E. Smet, H. Van Langenhove, Abatement of volatile organic sulphur compounds in odorous emissions from the bio-industry, Biodegradation 9 (1998) 273–284.

[6] K. Boholt, K. Andreasen, F. den Berg, T. Hansen, A new method for measuring emission of odour from a rendering plant using the Danish odour sensor system (DOSS) artificial nose, Sens. Actuat. B-Chem. 106 (2005) 170–176.

[7] P. Gostelow, S.A. Parsons, R.M. Stuetz, Odour measurements for sewage treatment works, Water Res. 35 (2001) 579–597.

[8] EN 13725, Air Quality-determination of Odour Concentration by Dynamic Olfactometry, Comité Européen de Normalisation, Brussels, 2003.

[9] United States Environment Protection Agency (US EPA), Compilation of Air Pollutant Emission Factors, AP 42, vol. I, fifth ed., Stationary Point and Area Sources, Research Triangle Park, NC, 1995.

[10] S. Sironi, L. Capelli, P. Céntola, R. Del Rosso, M. Il Grande, Odour Emission Factors for assessment and prediction of Italian MSW landfills odour impact, Atm. Environ. 39 (2005) 5387–5394.

[11] P. Mussio, A.W. Gynp, P.F. Henshaw, A fluctuating plume dispersion model for the prediction of odour-impact frequencies from continuous stationary sources, Atm. Environ. 35 (2001) 2955–2962.

[12] S. Sironi, A.N. Rossi, R. Del Rosso, P. Céntola, M. Il Grande, Odour impact assessment using dispersion modelling: a case study of an operatine landfill, in: T.H. Christensen, R. Cossu, R. Stegmann (Eds.), Proceedings Sardinia, CISA Pub., Cagliari, 1993.

[13] P. Gostelow, P.J. Longhurst, S.A. Parsons, R.M. Stuetz, Review of Odour Sampling and Measurement, Final Report for EB Milton Keynes Limited, School of Water Sciences, Cranfield University, 2003.

[14] P.J. Bliss, K. Jiang, T.J. Shulz, The development of a sampling system for determining odor emission rates from area surfaces. Part II. Mathematical model, J. Air Waste Manage. Assoc. 45 (1995) 989–994.

[15] W.M. Kays, M.E. Crawford, B. Weigand, Convective Heat and Mass Transfer, Mc Graw-Hill, New York, 1993.

[16] H. Schlichting, K. Gersten, Boundary Layer Theory, Springer-Verlag, Berlin Heidelberg, 2000.

[17] K. Jiang, P.J. Bliss, T.J. Schulz, The development of a sampling system for determining odor emission rates from area surfaces. Part I. Aerodynamic performance, J. Air Waste Manage. Assoc. 45 (1995) 917–922.

[18] J. Jiang, R. Kaye, Sampling techniques for odour measurement, in: Stuetz Richard, Frechen Franz-Bernd (Eds.), Odours in Wastewater Treatment: Measurement, Modelling and Control, IWA Publishing, London, 2001.

[19] J.H. Sohn, R. Smith, E. Yoong, J. Leis, G. Galvin, Quantification of odours from Piggery effluent ponds using an electronic nose and an artificial neural network, Biosyst. Eng. 86 (2003) 339–410.