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Analysis of Odor Nuisance Emitted by a Rendering Plant Processing Animal By-products, Which is Located in the Center of a Several-thousand Population Village

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Abstract: The constantly growing need for livestock production for food purposes generates huge amounts of animal by-products unfit for human consumption. Therefore, the number of rendering plants that facilitate the recovery of animal waste in the form of fat and protein flour constantly grows. Odors emitted from rendering processes can significantly impact air quality, causing nuisance for humans, especially when the plant is close to residential areas. This research focuses on the concentration of odour emission from thermal rendering operations determined by dynamic olfactometry and removal efficiency in the 3-stage water scrubber used in the investigated plant. Among the 6 process air stream emitters investigated, 3 presented the major odorous contributions according to their high odorant concentrations. The elimination of odour nuisance by a 3-stage water scrubber revealed a low removal efficiency of less than 55%. Such an outcome suggested inappropriate conditions such as alkaline pH and low odorant solubility in water. Thus, other removal methods need to be implemented to achieve satisfactory results.

Keywords: rendering plant, odour emission rate, olfactometry, animal by-products

1. Introduction

According to the International Organization for Standardization (ISO 5492: 2008), odour is defined as an organoleptic attribute precepted by the olfactory system by sniffing certain volatile substances, whereas odorant is a substance which stimulates a human olfactory system so that an odour is perceived (Blanco-Rodríguez et al. 2018). Odour nuisance has recently become one of the most frequently reported subjects of complaints concerning air quality (Falcone et al. 2020), representing a growing social problem in industrialised countries (Ranzato et al. 2012). Odour-emitting plants used to be located in the suburbs of cities or villages. Nowadays, the distance between residence and industrial areas is shortened as urbanisation constantly grows. Therefore, the odour nuisance problem has not only its ecological meaning but also is a growing social problem; actions aimed at odour reduction and control are currently needed (Henshaw et al. 2006). The assessment of odour nuisance can be performed as odour concentration measurement using dynamic olfactometry protocol (Capelli et al. 2011, Sowka et al. 2017, Gonzalez et al. 2022) or quantitative and qualitative analysis of odorous chemical compounds using instrumental methods (Dincer et al. 2006, Capelli et al. 2011, Capelli et al. 2014b).

Global demand for butcher products causes the scale of slaughterhouse operations immense. It returns exceedingly large volumes of animal by-product material that must be processed, sterilised and processed into value-added products (Meeker et al. 2006). Rendering is a global industry process of converting problematic animal by-products such as hides, skins, bones, feathers, heads, blood, fat tissues, egg shells and whole carcasses, etc., which are not intended for human consumption, into profitable products by extracting fat and protein from slaughter waste or dead animals (Bhatti et al. 2014). This process promotes the idea of a circular economy by recycling valuable nutrients, and it limits the transfer of hazardous pathogens to the environment through animal carrion sterilisation (Musmarra et al. 2019). However, as the process takes place at high temperatures and uses decaying material as a substrate, there are also high rates of odour emission occurring in the rendering plants (Luo et al. 2001). Odorous emissions are mainly caused by degradation, fermentation and thermal decomposition of the animal waste in cookers and drying operations (Omidi et al. 2019). The heating of animal by-product tissues promotes degradation reactions.

A few reports are pointing the scale of odour concentration values found in literature for rendering operations: Veira (Veira et al. 2016) mentioned average odour concentrations ranging from 50,000 and 100,000 $OU \cdot m^{-3}$ for viscera and blood cookers, whereas Luo and Lindsey (Luo et al. 2006) analysed exhaust gases from direct-fired meal dryers at an animal rendering plant and reported total odour concentration ranging from

50,000 to 307,200 $OU{\cdot}m^{-3}$. The authors attribute this large variation to differences in the type and amount of raw materials processed. Thus, it is essential to determine the variability of emissions with the highest possible temporal resolution to create reliable models of odour dispersion that would enable a credible assessment of the environmental impact of the rendering plant on the community. Such data would be an appropriate tool for decision-making in terms of choosing the best available waste gasses purification technologies to minimise odour influence on local society (Camro et al. 2010).

This study aimed to analyse the level of odour emission from a rendering plant in East Poland processing animal by-products category 3 in continuous and batch thermal processes. As the rendering plant was located in the middle of a few thousand inhabitants villages, such studies are needed to visualise the scale of the odour nuisance problem growing with the expansion of residential housing areas in Poland. Dynamic olfactometry was used to evaluate the odour abatement efficiency and identify areas of improvement. Additionally, waste gas's volumetric flow rate was evaluated to determine the odour emission rate and assess its removal effectiveness when wet scrubber installation was performed.

2. Materials and Methods

2.1. Scope of study

The study was performed at a rendering plant in Central and East Poland, which annually processes circa 100,000 tons of animal waste and by-products in category 3, defined as low risk. Rendering products are obtained from the thermal processing of high-fat animal by-products. The plant operates 24 hours a day, 6 days a week, from Monday to Saturday. The system consists of grinders, continuous cookers (horizontal steam jacketed cylinders equipped with a mechanical agitator), and batch and continuous dryers (central piped with vertically arranged and conical discs), each with a 10 m^3 volume. The process begins when high-fat raw materials are loaded into a large screw feeder with a grinder that feeds into continuous steam-heated cookers. The cooker operates up to 130°C and 5 bar. During high-temperature cooking, raw material turns into 3-phase pulp. The pulp is then centrifuged to separate 3 fractions: fat, protein meal and colloid water solution. The fat is further purified by the system of decanters and filters; protein meal is discharged into a press to separate the remaining fat, dried in dryers and flaked into mills. Colloid water solution is collected into tanks and transported to nearby biogas plants. The rendered products (protein meal or fats) are then stored in tanks and silos where from are packaged and distributed. The plant is divided into fat melting production area where animal by-products are stored, ground and transported to the cookers to melt and a meat and bone meal production area where the drying process is conducted.

Waste gases emitted from the processes were continuously extracted and condensed by water condensers for cooking and air condensers for drying. Both condensates were sent to the wastewater treatment plant, and the non-condensable fraction was mixed into the ambient air of the facility and then released into the atmosphere after treating into 3 stage water scrubber filled with Pall's rings. The vapours coming from cooking and drying operations, which are characterised by an intense odour charge, are defined as "process air". In contrast, the air coming from the department aeration systems and from free manufacturing areas, which are considered less odorous, is defined as "department air". The ventilation system was constructed as one for the whole rendering plant. Every process source had its own fan, forcing vapours into the collective ventilation duct. Manufacturing areas were ventilated by a collective ventilation duct, which ended with a fan. The final outlet of collective ventilation contained a mixture of process and department air.

2.2. Odour sampling and measurement

Samples for olfactometric measurements were collected following the VDI 3880 standard, "Olfactometry – Static Sampling" (VDI 3880:2011). The samples were collected into 10-L Tedlar® (polyvinyl fluoride, Sigma Aldrich) bags using a diaphragm vacuum sampling pump (GZ-79200-10, Cole-Parmer Instrument Co, USA), while the air sampling flow rate was adjusted using a rotameter. The air sampling flow rate was set at 0.5 L min^{-1}, and the sampling volume was 5-10 L. As the temperature of selected probes was high, the streams were primarily run through a cooling system to avoid condensation of humidity inside the Tedlar® bag. The probing scheme is presented in Figure 1.

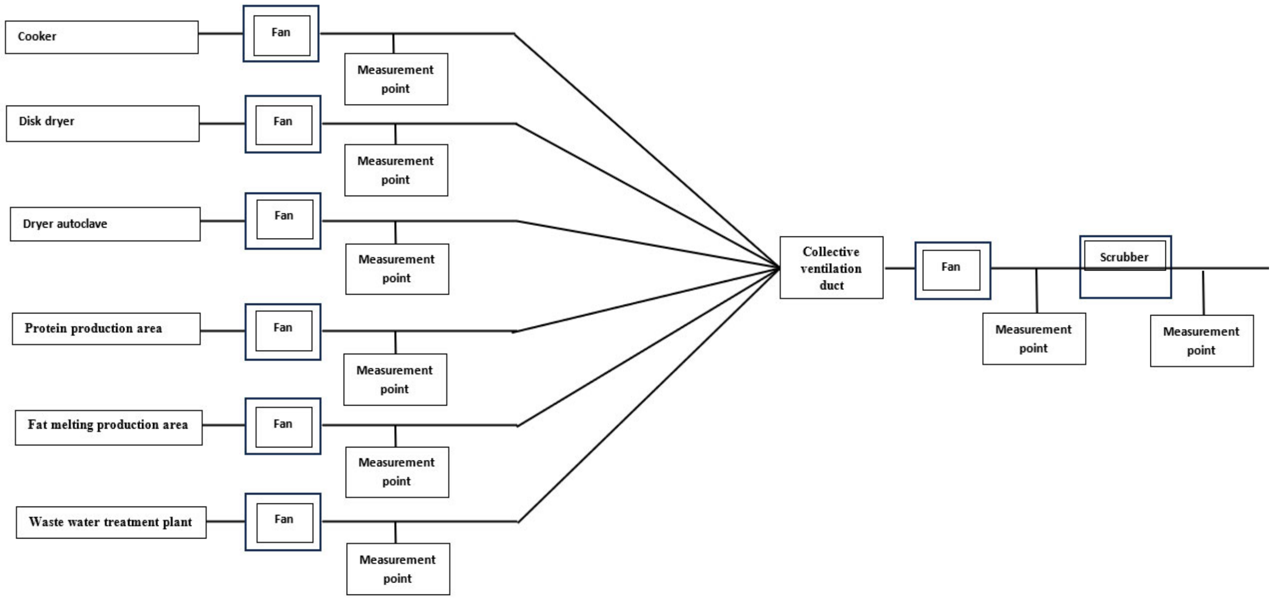

Fig. 1. Odour emission sources and measurement points scheme

Firstly, seven odour emission points were investigated separately during their working time. Three samples were collected for each odour emission point. Secondly, the collective ventilation duct was investigated successively through 6 production days of the working week in two points simultaneously: the suction part of the fan before the scrubber and the outlet of the scrubber ended with the chimney. The water scrubber was not supported with any chemical solutions to improve its efficiency. During the sampling procedure, parameters of the streams, such as volume flow rate (435-4, Testo, Germany), temperature, humidity and atmospheric pressure were measured (Hygro Palm 22-A/HC2-HK40, Rotronic, Switzerland).

In the next step, all the collected probes were immediately transported to the Olfactometry Laboratory. Odour concentration was determined with PN-EN: 13725 standard "Air Quality. Determination of odour concentration by dynamic olfactometry" (PN-EN: 13725:2007) using dynamic dilution olfactometer (TO8, Institut für Landw, Germany) basing on the "yes/no" method. The apparatus was equipped with four-panel lists' places in separate open boxes, each box equipped with a stainless steel sniffing port and push-button. The measuring range for the instrument started from a maximum dilution factor of 1/64 000 with a dilution step factor of 2. All analyses were performed within 24 hours after collecting the last probe in each set.

The amount of saporific compounds is expressed in odour unit (OU). One European Odour Unit, [$OU_E \cdot m^{-3}$], is the amount of odorant(s) evaporated into one cubic meter of neutral gas. $OU_E \cdot m^{-3}$ is calculated as the geometric mean of the individual threshold estimates of the panel members after retrospective screening.

Once the odour concentration was measured, it was possible to determine the Odour Emission Rate (OER) associated with each emission. The OER ($OU_E \cdot s^{-1}$) is calculated as the product of the odour concentration ($OU_E \cdot m^{-3}$), and the airflow ($m^3 \cdot s^{-1}$) conveyed to the odour abatement system. The odour emission rate was calculated according to VDI 3880 (VDI 3880:2011) as:

$$OER = Q_{air} \text{ x } C_{OD} \tag{1}$$

where:
OER – the odour emission rate [$OU_E \cdot s^{-1}$],
Q_{air} – is the effluent volumetric flow rate [$m^3 \cdot s^{-1}$],
C_{OD} – measured odour concentration [$OU_E \cdot m^{-3}$].

The odour concentration values (C_{OD}) measured at the inlet ($C_{OD}IN$) and outlet ($C_{OD}OUT$) of the odour wet scrubber were used for the calculation of the odour removal efficiency (ORE) according to the following equation:

$$ORE = \frac{CodIN - CodOUT}{\text{CodIN}} \tag{2}$$

3. Results

All the sources of odour emission in the rendering plant were analysed: batch cooker (BC), disk dryer (DD), drying autoclave (DA), protein production area (PPA), fat melting production area (FMPA), wastewater treatment plant (WWTP). The results of the average temperature, volumetric flow rate and velocity of the streams are presented in Table 2.

Table 2. Average temperature [°C], velocity [$m\cdot s^{-1}$] and volumetric flow rate [$m^3\cdot s^{-1}$] measured in each rendering operation waste gas stream

Source	Symbol	Average temperature [°C]	Average velocity [$m\cdot s^{-1}$]	Average volumetric flow rate [$m^3\cdot s^{-1}$]
Cooker	C	67.2 ± 0.1	4.7 ± 0.1	0.91 ± 0.1
Disk dryer	DD	19.3 ± 0.1	7.2 ± 0.1	0.55 ± 0.1
Dryer Autoclave	DA	20.1 ± 0.1	6.9 ± 0.1	0.37 ± 0.1
Protein production area	PPA	35.2 ± 0.1	8.5 ± 0.1	2.42 ± 0.1
Fat melting production area	FMPA	32.8 ± 0.1	7.3 ± 0.1	1.92 ± 0.1
Waste water treatment plant	WWTP	23.5 ± 0.1	0.7 ± 0.1	0.25 ± 0.1
Collective ventilation duct	CVD	35.7 ± 0.1	8.9 ± 0.1	9.81 ± 0.1

The olfactometric analyses of waste gases emitted from each source showed significant differences in the odour emission values. The highest odour concentration was obtained for dryer autoclave [DA], (294,300 $OU_E\cdot m^{-3}$), disk dryer [DD], (278,412 $OU_E\cdot m^{-3}$), and cooker [C] (145,374 $OU_E\cdot m^{-3}$), whereas lower odour concentration was obtained for wastewater treatment plant [WWTP], (26,043 $OU_E\cdot m^{-3}$), protein production area [PPA], (9,541 $OU_E\cdot m^{-3}$) and fat melting production area [FMPA], (2,884 $OU_E\cdot m^{-3}$), Figure 2.

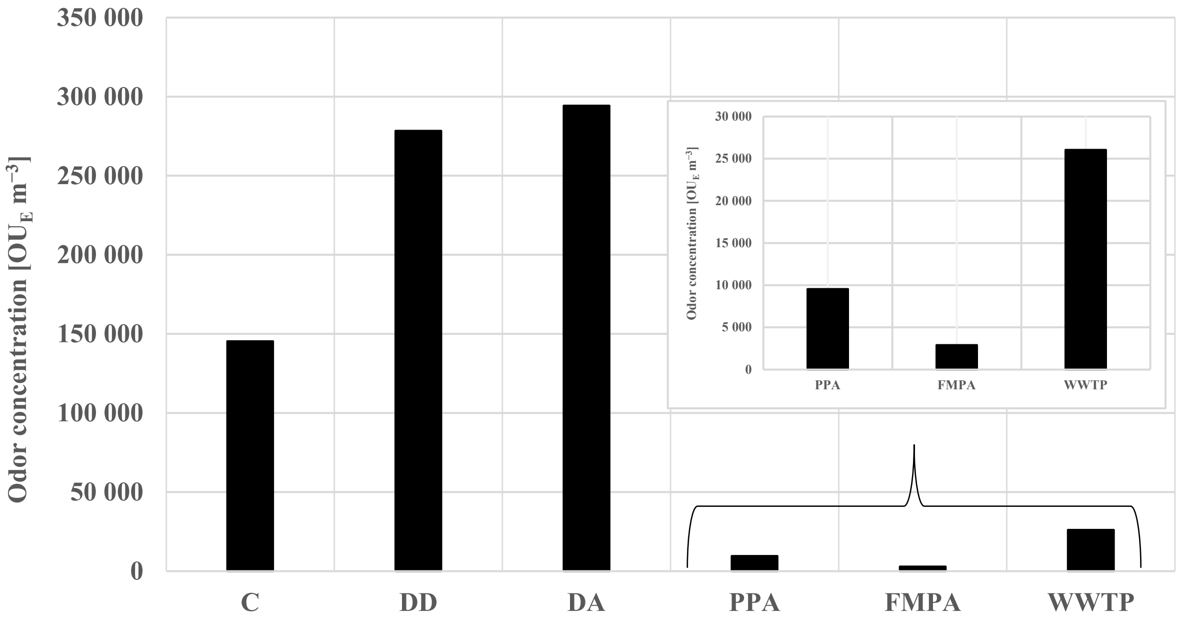

Fig. 2. Odour concentration [$OU_E\cdot m^{-3}$] determined by dynamic olfactometry from high-temperature rendering processes waste gas streams: C – cooker, DD – disk dryer, DA – drying autoclave, FMPA – fat melting production area, PPA – protein production area

The olfactometric analyses of the odour emission rate directly from each source showed significant differences in the odour emission rate values. The highest odour result was obtained for the disc dryer [DD] (154,287 $OU_E \cdot s^{-1}$), cooker [C] (132,775 $OU_E \cdot s^{-1}$) and autoclave dryer [DA] (109,545 $OU_E \cdot s^{-1}$), whereas lower odour concentration was obtained for protein production area [PPA], (23,110 $OU_E \cdot s^{-1}$), wastewater treatment plant [WWTP], (6,561 $OU_E \cdot s^{-1}$) and fat melting production area [FMPA], (5,540 $OU_E \cdot s^{-1}$), Figure 3.

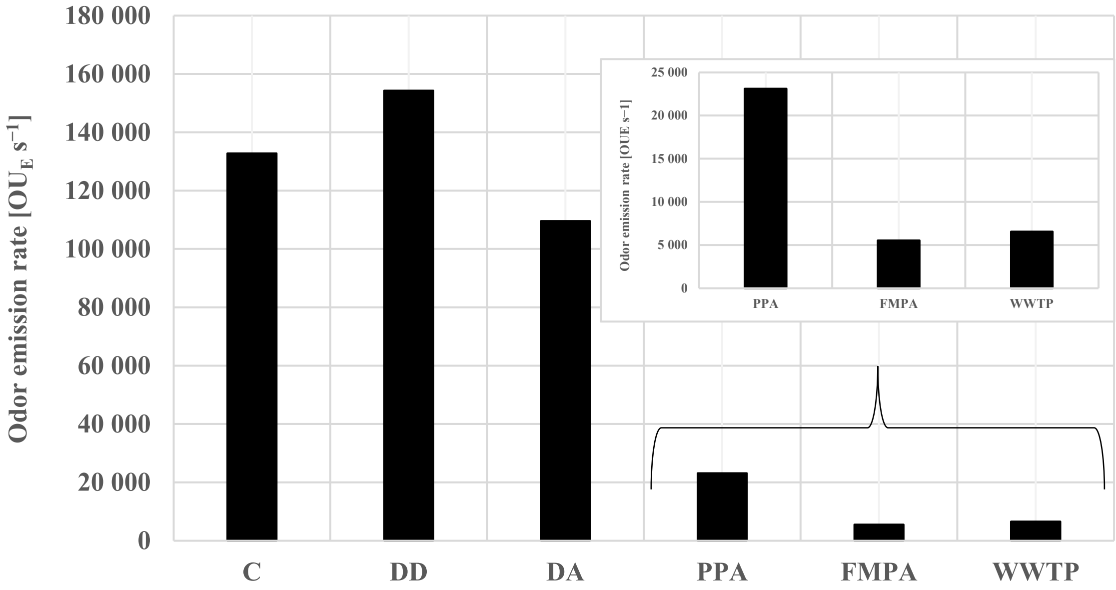

Fig. 3. Odour emission rate [$OU_E \cdot s^{-1}$] determined by dynamic olfactometry from high-temperature rendering processes waste gas streams: C – cooker, DD – disk dryer, DA – drying autoclave, FMPA – fat melting production area, PPA – protein production area

The olfactometric analyses of total OER measured in the collective ventilation duct before scrubber through six consecutive days of production, starting Monday, showed significant differences in the OER values. The highest OER result was obtained for 5th day, 446,579 $OU_E \cdot s^{-1}$, and 6th day, 395,767 $OU_E \cdot s^{-1}$ whereas lower OER was obtained for 4th day, 347,275 $OU_E \cdot s^{-1}$, 3rd, 319,947 $OU_E \cdot s^{-1}$, 2nd 298,492 $OU_E \cdot s^{-1}$ and the lowest OER was obtained for 1st day, 117,463 $OU_E \cdot s^{-1}$, Figure 4. The average OER, obtained as a geometric mean of the mean OER values, is 310,920 $OU_E \cdot s^{-1}$. The standard deviation associated with this value equals 118,048 $OUE \cdot s^{-1}$ and the median equals 333,611 $OU_E \cdot s^{-1}$. The lowest OER obtained on the 1st day of production week was caused by the fact that only one drying process was conducted in its very beginning phase while cooking other drying processes were stopped. On the other hand, the highest OER obtained for the 5th day of production week occurred when all the processes were conducted with full efficiency.

The olfactometric analyses of total odour concentration measured before and after treatment in a wet scrubber through six consecutive days of production, starting Monday, showed low odour removal efficiency (ORE) values. The average ORE obtained as a geometric mean of the mean odour concentration values is 45.2%, Figure 5. The standard deviation associated with this value equals 12.5%, and the median equals 49.8%. A very low-efficiency value for wet scrubber odour removal method does not have to indicate that scrubbers are unsuitable for reducing odours in rendering plants. As said in the beginning, the wet scrubber installation in the analysed rendering plant performed without any chemical support, increasing its efficiency. Moreover, no data is available on the frequency of the absorption liquid changing. In fact, the removal efficiency of scrubbers can be raised by frequently changing the absorption liquid and adding specific reactants to the water solution.

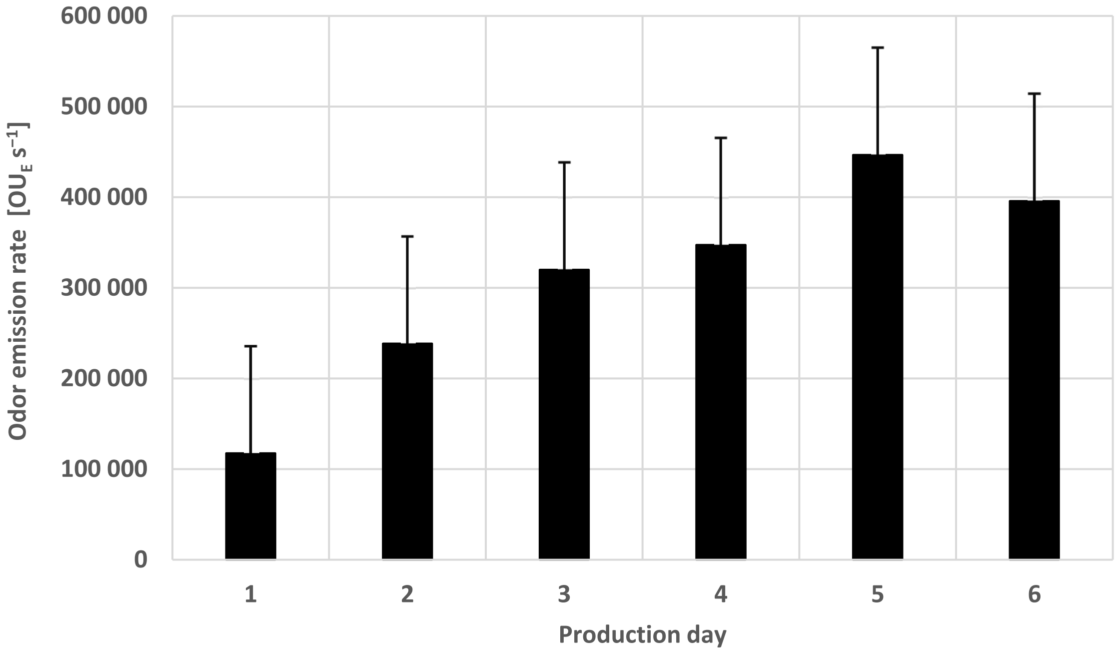

Fig. 4. Odour emission rate [$OU_E \cdot s^{-1}$] determined by dynamic olfactometry in collective ventilation duct before scrubber containing high-temperature rendering processes waste gas streams defined as "process air" mixed with "department air" from ventilating production areas measured through one week of plant operation starting from Monday as day 1 and finishing on Saturday as day 6

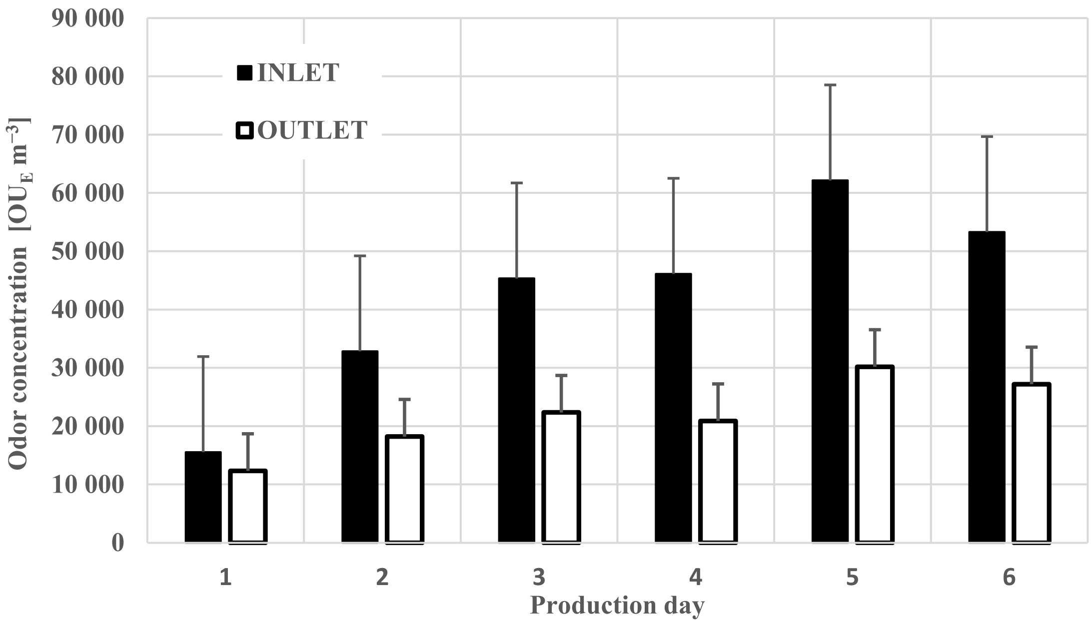

Fig. 5. Odour concentration [$OU_E \cdot m^{-3}$] determined by dynamic olfactometry in the inlet and outlet of the wet scrubber that conditioned total odour stream containing high-temperature rendering processes waste gas streams defined as "process air" mixed with "department air" from ventilating production areas, measured through one week of plant operation starting from Monday as day 1 and finishing on Saturday as day 6

4. Conclusions

This study analysed odour concentration, odour emission rates, and its removal efficiency during production operations at the rendering plant. The highest odour concentration, 294,300 $OU_E \cdot m^{-3}$, was obtained for drying operations and the highest odour emission rate for drying operations, 154,287 $OU_E \cdot s^{-1}$, as well. Nevertheless, odour concentration and emission rate for cooking operations were also high, reaching 145,374 $OU_E \cdot m^{-3}$ and 132,775 $OU_E \cdot s^{-1}$ values. Both drying and cooking processes contributed significantly to the total odour emission rate, which was 310,920 $OU_E \cdot s^{-1}$ on average, reaching the highest value (446,579 $OU_E \cdot s^{-1}$) on the 5th day of production week as all the processes were conducted simultaneously with full efficiency. Notably, the average odour concentration in untreated gas determined in this study represents all steps of the process (mixed gas streams), which converged to a single treatment point.

The results cited by Vieira et al. (2016) should be mentioned in reference to the odour concentration values found in similar industrial processes. Authors reported average odour concentrations of about 50,000 and 100,000 $OU \cdot ft^{-3}$ for viscera and blood cookers, respectively, and 800 $OU \cdot ft^{-3}$ for blood dryers. Luo et al. (2006), who studied pilot-scale biofilters to treat exhausted gases from meal dryers at an animal rendering plant, reported influent odour concentrations ranging from 50,000 to 307,200 $OU \cdot m^{-3}$. The authors attribute this large variation to differences in the type and amount of raw materials processed.

Sironi et al. (2007), in their study on odour emission of Italian rendering plants, estimated odour emission factors of 4.52 × 108 $OU \cdot t^{-1}$ for 'process air' (i.e. odorous air streams from cooking, boiling and pressing operations) and 8.02 × 107 $OU \cdot t^{-1}$ for a mixture of 'process air' and 'department air'. The latter authors reported inlet odour concentrations varying from 160,000 to 180,000 $OUE \cdot m^{-3}$.

Even though the calculated values of odour emission rate from each source present considerable differences between "process air" and "department air", the relevance of the obtained OER demonstrates that none of the emission types may be ignored in the odour impact determination of a rendering plant. Both types of source streams mixed in the collective ventilation duct were passed through the wet scrubber with no chemicals applied in absorption liquid, reducing total OER by 45.2% on average (SD = 12.5%).

As presented by Sironi et al. (2007), the efficiency for odour removal values relevant to wet scrubbers were very different from each other in the group of six investigated rendering plants, ranging from 23.8% to 87.1%. As the author explained, in general, these differences did not necessarily indicate that wet scrubbers are inappropriate 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.

The OERs determined in this study can be very helpful for applying specific odour dispersion models, which enable the prediction and estimation of the odour impact of a rendering plant. This kind of estimation enables the evaluation of the area intended for either building or expanding a rendering plant, considering the odour nuisance for society living nearby.

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