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Review article

Analyses of odours from concentrated animal feeding operations: A review

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ABSTRACT

Concentrated Animal Feeding Operations (CAFOs) are widely present all over the world due to the high population demand for food and products of animal origin. However, they have generated several environmental concerns, including odour nuisance, which affects people health and quality of life. Odours from livestock are a very complex mixtures of molecules and their analytical investigation is highly demanding. Many works have been published regarding the study of odours from CAFOs, using different techniques and technologies to face the issue. Thus, the aim of this review paper is to summarize all the ways to study odours from CAFOs, starting from the sampling methods and then treating in general the principles of Dynamic Olfactometry, Gas Chromatography coupled with Mass Spectrometry and Electronic Noses. Finally, a deep literature summary of Gas Chromatography coupled with Mass Spectrometry and Electronic Noses applied to odours coming from poultry, dairy and swine feeding operations is reported. This work aims to make some order in this field and it wants to help future researchers to deal with this environmental problem, constituting a state-of-the-art in this field.

1. Introduction

During the last decades, the global population growth has implied an increased demand of food of animal origins, such as meat, eggs and milk, with the consequent intensification of livestock production systems. A large number of concentrated animal feeding operations (CAFOs) have been recently built in many parts of the world (Cai and Koziel, 2011). Therefore, these practices have led to several environmental issues, such as increased ammonia, greenhouse gases, odours, particulate matter (PM) and volatile organic compounds (VOCs) emissions into the atmosphere (Bibbiani and Russo, 2012; National Research Council US, 2003).

Odours emitted from CAFOs are generated directly from animals, bedding and faeces (Carey et al., 2004). They are not constituted by a single compound, but rather by a complex mixture of hundreds of diluted volatile substances, which make difficult their identification, quantification and abatement. The US Environmental Protection Agency (US EPA) does not regulate odours with specific federal standards, but considers them as a nuisance, which is defined as interference with the normal use of property (Carey et al., 2004). Indeed, odorous emissions from livestock often generate conflicts between farmers and their neighbourhood (Romain et al., 2013), due to the unpleasant smell, and this causes a decline in the surrounding properties value (Cai and Koziel, 2011). Moreover, these odours have generated concerns about health and welfare of both animals and humans working inside or living nearby these facilities (Lovanh et al., 2016). Livestock malodours could induce emotional stress, anger and physical symptoms in population living nearby CAFOs (Schiffman, 1998). Thus, it is of primary importance to possess reliable analytical techniques to study odours, in order to develop appropriate abatement technologies and mitigation strategies, aimed to reach a greater environmental sustainability of livestock production. In addition, the sampling step is a critical point, which should be carefully performed to have representative samples, avoiding wrong conclusions and results after the following analyses (Bibbiani and Russo, 2012). Moreover, it must be noticed that odour composition and concentration depend on several factors, such as temperature, ventilation rate, relative humidity, age of the birds, season, dietary composition, litter type and bird stocking density (Pan and Yang, 2007), and this makes odours evaluation very demanding.

Given the complexity of the problem, this review paper summarizes the techniques to collect and analyse odorous sample, firstly from a general point of view and then regarding their application in the study of odours from poultry, dairy and swine CAFOs. In particular, Section 2 is focused on odour sampling methods, Section 3 regards instrumental and not instrumental techniques devoted to study odours and finally Section 4 concerns the application of gas chromatography coupled with mass spectrometry (GC-MS) and electronic noses in the evaluation of

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odours from CAFOs. The aim of the work is to make some order in the field of odour evaluation from CAFOs, resuming all the previous papers and laying the foundations for future researchers that want to deal with this problem.

2. Field air sampling

When an odour is encountered, the first thing to do is to correctly sample it. Air is sampled by means of three different techniques: polymer bags (Section 2.1); metal canisters (Section 2.2); sorbent tubes (Section 2.3) (Brattoli et al., 2011; Koziel et al., 2005). In polymer bags and in metal canisters, air is captured in its entirety (as a whole "body"), while in sorbent tubes the gaseous sample passes through a solid sorbent that adsorbs the volatile compounds (Woolfenden, 2010). A brief explanation about these sampling tools and methodologies is given below.

2.1. Polymer bags

Polymer bags are light, easy to use and low cost tools useful to sample the air in its entirety. Their filling is achieved by means of a pump and they can be made of two different polymeric materials: Tedlar (Pau et al., 1991) or Nalophan (Hansen et al., 2011). Many works have been focused on the factors that can modify the gaseous sample inside the bag and how these can affect the following analysis. Examples of factors that can lead to serious mistakes are the release of contaminants from the inner surface of the bag to the sample, chemical instability of the sample, sorption of the molecules of the sample on the inner surface of the polymer, storage time and temperature, light exposure of the bag and humidity of the air sample (Boeker et al., 2014; Capelli et al., 2014; Ghimenti et al., 2015; Ghosh et al., 2011; Hansen et al., 2011; Le et al., 2013, 2015; Szyłak-Szydłowski, 2015; Trabue et al., 2006; Van Durme and Werbrouck, 2015; Van Harreveld et al., 1999; Van Wang et al., 1996; Zarra et al., 2012).

2.2. Metal canisters

Metal canisters are pre-evacuated metal containers that do not require a pump for their filling, which is achieved by regulating a valve. These systems are robust but more expensive than polymer bags (Wang and Austin, 2006) and also in this case losses and modification of the gaseous sample could happen inside the canister (Koziel et al., 2005; S. Trabue et al., 2008).

2.3. Sorbent tubes

Sorbent tubes are glass or metal tubes packed with one or more solid sorbents, often polymeric materials or activated carbon (Woolfenden, 2010). They are portable and low cost, but they require a pump to sample the volatile compounds dispersed in the air. In addition, a thermal or solvent extraction of the adsorbed molecules is necessary for their analytical identification and, eventually, quantification (Brattoli et al., 2011). In some cases, a single solid sorbent is not able to retain all the volatile compounds present in the sample and so sorbent tubes packed with multiple sorbent materials are suggested (Smith et al., 1977).

In all these cases, some considerations must be pointed out. Firstly, a sampling system should ensure the sample integrity (Trabue et al., 2006) and the following analysis should be performed as soon as possible. In addition, pre-cleaning of the sampling device with pure air could be necessary (Laor et al., 2010). Lastly, choosing strategic points to sample air in large areas is an issue that must be carefully considered (Abdullah et al., 2012; Capelli et al., 2014).

3. Tools to study the sampled odours

After the sampling step, three methods to study odours exist: Dynamic Olfactometry (Section 3.1), Gas Chromatography coupled with Mass Spectrometry (Section 3.2) and Electronic Noses (Section 3.3).

3.1. A sensorial method: Dynamic Olfactometry

An odour is a mixture of volatile chemical compounds that humans and other animals perceive with the sense of olfaction and Dynamic Olfactometry is a technique that allows to assign to an odour its concentration, which is defined as the number of dilutions with odourless air required for an odour to be detected by 50% of a panel of human evaluators (CEN, 2003). Odour concentration is expressed in European odour units (OU_E), where one odour unit is defined by the European Standard as equivalent to the response elicited by one European reference odour mass, most commonly 123 μg n-butanol evaporated into 1 m^3 of neutral gas, with a resulting concentration of one $OU_E\ m^{-3}$ (CEN, 2003).

Measurements are performed with an olfactometer, which is a dilution instrument (made of inert and odourless materials) that presents the odour under investigation, diluted with odour-free air at different ratios, to a panel of human assessors. Examiners are selected after sniffing the reference gas n-butanol (Van Harreveld et al., 1999) and they should satisfy the following requirements:

- Average n-butanol odour threshold between 20 ppb and 80 ppb;
- The antilogarithm of the standard deviation of individual responses less than 2.3.

Samples are presented to the panelists from the more to the less diluted, in order to avoid getting the olfactory system used to the previous presented odour (Brattoli et al., 2011). Two operative methods exist to determine odour concentration by means of Dynamic Olfactometry (Ueno et al., 2009): the Yes or No Method and the Forced Choice Method. In the first one, the sample leaves only from one port of the olfactometer and the assessor answers yes if he/she smells an odour, no if he/she does not. In the other one, there are more than one active ports, but the odour goes out only from one of them, while odourless air leaves from the others. Evaluators say if they smell an odour from one of the ports.

Odour intensity is the perceived strength of odour sensation. It shares a logarithmic relationship with odour concentration (Misselbrook et al., 1993) and so the dilution ratios of the samples presented to panelists are chosen following a logarithmic function. For a dynamic olfactometer, the odour concentration C is given by:

$$C = (Q_O + Q_f)/Q_f$$

where Q_O is the flow of the odorous sample and Q_f is the flow of the odour-free air required to reach the threshold (Brattoli et al., 2011). Once each panelist has perceived an odour, the geometric mean between the concentrations of the last negative and the first positive answer is calculated and this is the odour concentration detected by each assessor. Then statistical calculations are performed to give a global result and exclude unreliable data (CEN, 2003).

In addition to odour concentration, other measurements (called Parametric Sensory Measurements) can be done to completely characterize an odour (Brattoli et al., 2011). To be more precise, these are:

- The odour character, based on specific dictionaries;
- The aforementioned odour intensity, based on specific scales;
- The hedonic tone, which quantifies how much an odour is pleasant or unpleasant.