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Non-thermal plasma for odour reduction from pig houses – A pilot scale investigation

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HIGHLIGHTS

- Low energy non-thermal plasma for odour reduction from a pig house.
- Negative corona discharge slightly better than positive corona discharge.
- Highest removal efficiencies were observed for indole and 3-methyl-1H-indole.
- Production of ethanol, 2,3-butanedione and dimethyl trisulphide.
- Above 90% particle reduction for most experiments and settings.

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ABSTRACT

This study was performed to investigate if a low energy non-thermal plasma (NTP) system can be a realistic technology for treating odour from livestock production, which requires solutions that can treat large air volumes at a low cost. A pilot NTP system for odour removal was installed on a slip stream of ventilation air from a pig house. Both negative and positive corona discharge modes were utilised. Selected odorants were measured chemically by the use of proton-transfer-reaction mass spectrometry (PTR-MS). Particle removal due to electrostatic effects was also investigated. Highest removal efficiencies were observed for indole and 3-methyl-1H-indole at both positive and negative modes while significant removal was also observed for methanol, 4-methylphenol, and 4-ethylphenol. The results showed production of ethanol, 2,3-butanedione and dimethyl trisulphide. Negative voltage gave slightly higher removal efficiency than positive voltage, but it also gave a higher ozone production, which is not desirable. The results were analysed using a principal component analyses (PCA). Possible mechanisms are discussed in order to account for differential degradation of the odorous compounds. Particles were removed with above 90% efficiency for all experiments at a flow of 135 m^3/h and voltages from 15 to 45 kV.

1. Introduction

Odour emission from pig production is an increasing problem as new pig houses tend to be larger and the production is increasingly intensified. In addition the neighbouring communities are growing closer to the farms.

Odour emissions that are a nuisance to neighbouring communities should be dealt with as a serious problem as studies have shown that it results in a reduction in life quality and might cause health problems [1]. Several different negative effects on health, like certain respiratory and gastrointestinal problems and mucous membrane irritation, have been discovered at higher frequency among people living close to hog operations compared to residents of communities with no intensive livestock operations [2]. Aatamila et al. [3] found a consistent but not strong association between reported odour annoyance from waste treatment processes and physical symptoms, and they found that the physical symptoms were more clearly associated with odour annoyance than with odour perception. According to a study by Schiffman et al. [4] odours from swine operations can have a significant negative impact on mood of nearby residents, and they therefore recommend that methods should be found to lower the compounds responsible for the odour.

Recent studies of odorant composition and odour-odorant correlations indicate that volatile sulphur compounds, alkyl-phenols, short-chain carboxylic acids and indoles provide important contributions to perceived odour, although no definitive short-list of key odorants can presently be provided [5–8]. For further information, see [5–8] and discussions therein.

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It is common to find high concentration of particulate matter inside a pig house, often 10–100 times higher than the concentration in other indoor environments [9]. Odorants may be trapped in particles as well as in the gas phase [10] and the inhalation of dust can cause negative health effects. The emission of particles is therefore important to control.

The standards and regulations for airborne emissions are being increasingly stringent in Europe [11]. This creates a need for robust and cost-efficient abatement technologies of which end of pipe air treatment is one potentially relevant approach. In livestock production, the air volumes to be treated are large and for a treatment system to be a realistic solution the cost needs to be low.

There are many methods for odour removal, e.g. active carbon, wet scrubbing, biofilters, incineration and ozonation, but they all have limitations technically and economically. Today biofilters are the only realistic solution for livestock production. Biological air filters for pig farms have been developed at a commercial scale and they have shown to be able to reduce both odour and ammonia. For full scale installations the removal efficiency reported in the literature shows fluctuations (e.g. from ∼0% to 99% for odours) [12,13]. Martens et al. [14] achieved average odour reduction between 40% and 83% by using biofilters on emissions from pig facilities. At ideal conditions in lab scale removal efficiency of 100% has been shown, but for on-site situations it is usually much lower for the individual compounds [12]. Maintaining proper conditions are important to achieve high removal efficiencies. A drawback with biological treatment is that it is difficult to control and it is not flexible towards variable loading of contaminants. High removal efficiency of ammonia has been demonstrated by acid scrubbers, but they have low effect on the odour [13].

Treatment of ventilation air by the use of non-thermal plasma (NTP) is a promising alternative technology for odour removal [15–17]. Some of the advantages with NTP systems are that they are low in cost and small in size. They have a low pressure drop and have previously shown high removal efficiencies for volatile organic compounds [17–19]. Jarrige and Vervisch [16] presented high removal efficiencies for dimethyl sulphide (DMS) and hydrogen sulphide (H_2S) at high power inputs (e.g. Specific Input Energy (SIE) as high as ∼80 Wh/m^3 depending on concentration and compound). Tsai et al. [20] investigated reaction mechanisms and decomposition of methanethiol (MT) by NTP. A study by Sano et al. [21] showed that acetaldehyde and skatole can be removed from N_2 by the use of corona discharge. A packed bed ferroelectric plasma reactor has shown high removal of ammonia and odorous compounds from animal houses [22]. Particles can be removed from air streams by the electrostatic effect and experiments on particle removal from a poultry farm by an electrostatic precipitator gave removal efficiencies as high as 79% and the efficiencies were as high as 95% for fine particles [23].

The NTP used in this study is created by high voltage. DC voltage is applied to a corona wire and results in a silent discharge between the wire and the cell wall of the plasma reaction chamber. Electrons are bombarding the bulk gas molecules which results in production of excited gas molecules such as (N_2^*, O_2^*). The excited molecules lose their excess energy by emitting photons or producing heat. Ionisation, dissociation, electron attachment and other processes will also occur in the discharge zone [16,24]. This results in formations of unstable reactive species like ions and free radicals. The free radicals are highly reactive and therefore ideal for conversion of environmental pollutants to CO_2, H_2O and other degradation products [16,24]. The $OH^{\cdot}$ radical is considered to be the most important species in the non-thermal plasma system [18].

Full scale NTP systems for waste gas cleaning are currently operative [19,24,25]. NTP is already in use for reducing the odour nuisance from different emission sources like tobacco factories, pet food and fish feed.

Only tentative tests have been conducted to investigate the suitability of treating emissions from pig production by NTP systems. Further research and development is needed in order to verify the effect of this technology and to optimize the application. More knowledge is important to be able to understand the processes happening in the reaction chambers and to be able to optimize the systems to obtain the best possible odour reduction and air cleaning at a reduced cost.

The aim of this study was to investigate the performance of the low energy NTP system for odorant reduction and removal of dust from emissions from pig houses. For measuring individual odorous compounds, proton-transfer-reaction mass spectrometry (PTR-MS) was used. NTP systems also have a great potential for removal of particulate matter due to electrostatic effects and particulate matter was measured in this study to document these effects for the specific corona discharge geometry and power input. In addition to the treatment of pig house ventilation air, experiments based on a few individual compounds, H_2S, DMS and MT, were conducted. This was done in order to check for differences in removal efficiency in the absence of dust and co-contaminants.

2. Materials and methods

The effect of a NTP scrubber on odour from pig houses was tested. In the experiments a small scale pilot test system was used. This consisted of a reaction chamber which is shaped as a 1 m long hexagonal cell where each side is 8 cm wide. A corona wire was running through centrally and a high voltage generator distributed a high frequency (35 kHz) modulated high voltage to the corona wire. The shortest distance from the wire to the cell walls was about 7 cm.

In the experiments different voltages and different flows through the equipment were tested. Both negative and positive voltages were applied by using pilot systems provided by Applied Plasma Physics AS. High frequency Switch Mode Power Supplies (SMPS) provided a continuous DC signal with less than 3% ripple.

The experiments were conducted in an experimental pig house at Research Centre Foulum, part of Aarhus University in Denmark. The facility was equipped with a diffuse inlet through the ceiling and two types of ventilation outlets; one in the room (through the ceiling) and one mounted in the pit. Odorous air for the experiments was sampled from the pit ventilation duct and treated in the NTP system. Measurements were performed sequentially in the inlet and the outlet of the NTP system. Odorous air from a partial pit ventilation system was chosen as a study by Hansen et al. [5] on a similar ventilation system showed that odorants can be concentrated in the air from the pit and by treating only a small amount of the ventilation air, the cost will be lower compared to treatment of all the ventilation air.

Two experimental series with constant flow and variations in voltage were tested. The flow was kept at 135 m^3/h (∼2.4 m/s), which is equivalent to modular system capacity of 20,000 m^3/h for full scale installations of the system for treatment of odour from e.g. pet food production. One series were run with positive voltage and one with negative. The voltage was varied from 10 to 45 kV. One series with positive and one with negative voltage was also run were the voltage was kept at 40 kV and the flow was varied between 67 and 270 m^3/h.

Additional experiments were conducted by introducing 100 ml/min 1000 ppm H_2S, DMS and MT to an airflow taken from the room outside the pigpens and measuring in the inlet and outlet. Two flow levels were tested, 45 and 70 m^3/h. Voltages between 38 and 43 kV were supplied to the reaction chamber by the positive and the negative generator. The power varied between 118 and 179 W.