Ammonia volatilization from manure application to field: extrapolation from semi-controlled and controlled measurements to emissions in real agricultural conditions

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Abstract

The mechanistic model Volt'air can predict ammonia volatilization in a wide range of climatic, soil and slurry conditions. In previous work it was shown that when slurry is represented as a specifically parameterized surface layer can clearly improve the outputs of the model. At this work different values of the boundary layer resistance were tested, over a soil/slurry/water surface, based in a laboratory experiment using ammonia volatilization flux chambers when different air temperatures and velocities were applied. The numerical results of the model can help in establishing an extrapolating tool used to generate "real" ammonia volatilization fluxes after manure application on the soil.

Introduction

Ammonia emission reduction is of major concern for United Nation's Economic Commission for Europe (UNECE) which addresses it in the Göteborg Protocole (1999) of the Convention on Long-Range Transboundary Air Pollution (LRTAP) to Improve Air Quality. Ammonia emission control requires a better knowledge and a better quantification of sources, especially after field application of manure and fertilizers. In the literature there are studies for standardization of flux chamber and wind tunnel flux measurements especially at animal feeding operations [1-4].
There is however no experimental method easy to operate in the field at the scale of the plot that would enable to perform experiments in a sufficient number as to provide data devoted to the establishment of a reference for ammonia volatilization as function of soils, manure or fertilizer types and climatic conditions. For this reason we proposed and designed:
(i) a field volatilization set-up, the wind-tunnels, well suited for the comparison of treatments carried out on small plots under semi-controlled condition;
(ii) a laboratory volatilization set-up aiming at precisely characterizing the ability of any soil, commercial fertilizer or organic manure to volatilize in well controlled and standardized conditions (see Flura et al., this conference). It is dedicated to the screening of the soils and fertilizers under standardized conditions which will be helpful to constitute references and typologies as regards volatilization.
This study aims at providing to both these set-ups a mathematical tool, which will allow calculating the ammonia volatilization that encounters in real field conditions, useful for diagnosis and decision making. The first step addressed theoretical considerations and dedicated experiments to characterise the regime of the air flow (laminar or turbulent) and to determine the exchange coefficient within the wind-tunnel and the volatilisation chamber. Particularly, boundary layer resistance (r_b) was calculated and measured under different conditions: it will be used to allow the extrapolation from the wind-tunnel/volatilization chamber to the field. The second step is the parameterization work done using the Volt'Air model [5, 6].

Materials and Methods

Ammonia volatilization measurement set-ups

The field volatilization set-up is based on the classical wind-tunnels as first described by Lockyer et al. (1984) [7] and adapted by Loubet et al. (1999a) [8] in order to improve their accuracy. The method is based on the mass balance of ammonia in a delimited volume of air circulating above the 1 m^2 emitting surface at about 1 m s^{-1}. Within the tunnel, the turbulent flow drives the transfer processes above the experimental surface. Specific experiments have been carried out [9] to determine the transfer characteristics within the tunnel. The laboratory volatilization set-up is based on the classical volatilization chambers and adapted from that of Le Cadre et al. (2005) [10]. The chambers are specifically designed in order to (i) host intact soil/manure cores in their sampling ring and (ii) ensure the homogeneity of the NH_3 emission over the entire surface of the sample, in laminar air flow. The volatilisation chambers are placed in a thermostatically controlled enclosure. Air supplied at the entrance is free of ammonia, thermostatically controlled and humidified (Fig. 1). Air flow rate is controlled in a range of 0 to 10 L min^{-1}. Air temperature, humidity and flow rate were chosen as a better compromise between their known influence on ammonia volatilisation variation and technical constraints. For more details, see the paper of Flura et al (this conference).

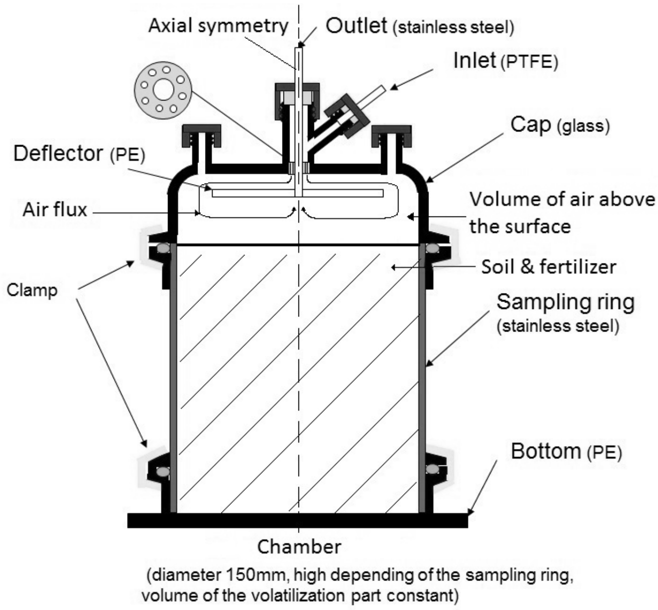


Figure 1. Volatilization chambers used in the present study.

Tool for extrapolation

The tool for extrapolation is built from the process-based model of ammonia volatilization in the field Volt'Air [5, 6]. It has been developed for simulating ammonia volatilisation after liquid organic waste and synthetic fertilizer application on arable land. It consisted in several sub-models that simulate the application of organic and mineral fertilizers, the chemical and physical equilibria between the various species of ammoniacal N in the soil, the transfer of heat, water and ammoniacal N within the soil, and the transfers of ammonia, heat and evaporation between the topsoil and the lower atmosphere. Processes are simulated with short time intervals over several days, or several weeks following the application of ammoniacal nitrogen in the field. The model can operate at an hourly time-step and has the capability to simulate several emission abatement methods such as timing of application, changing fertilizer characteristics and incorporation of the fertilizer following application.

Theoretical considerations to implement Volt'Air for the transfers of ammonia, heat and evaporation between the topsoil and the lower atmosphere sub-model will include parameterization of the boundary layer resistance inside the sub-models of energy balance and sensible heat. Boundary layer resistance (r_b) can be calculated by the Eqs 1 & 2 [11, 12]:

$$r_b = \frac{\rho c_p (T_s - T_a)}{H} \quad \text{(Eq. 1)}$$

$$r_b = \frac{D^{-2/3} \nu^{1/6}}{C} \left(\frac{d}{u} \right)^{1/2} \quad \text{(Eq. 2)}$$

where, ρ is the density of the air (kg m^{-3}), c_p is the specific heat (J g^{-1} K^{-1}), (T_s-T_α) is proportional to the temperature difference between the soil surface and a reference height in the atmosphere (K), H is the sensible heat flux (W m^{-2}), D is the molecular diffusivity (m^2 s^{-1}), ν is the kinematic viscosity of the air (m^2 s^{-1}), C is a constant, d is the length (m) and u is the wind speed (m s^{-1}).

Numerical and experimental tests

A computational fluid dynamics code (Comsol) using the Finite Element method, (http://www.comsol.com/), was used to for determining the streamlines and velocity field inside the laboratory volatilization chamber.

In parallel with the experiment carried out within the wind tunnels [8, 9], specific experiments were carried out with the chambers in order to (i) explore in which domain between laminar and turbulent transfers occur and (ii) determine the transfer characteristics/coefficient within the chambers. Both water and heat instead of ammonia volatilisation were chosen for this characterisation, because it is much easier to control either evaporation or heat exchanges and to measure air humidity or temperature respectively than ammonia concentration. Different values of r_b were obtained for:

(1) different conditions of sensible heat: a metallic plate figuring the soil surface was heated using a constant power, ambient temperature was fixed at 15°C, and several air flow rates were chosen between 0 and 10 L min^{-1}.

(2) different conditions of latent heat: the substrate in the chamber was water which quantity was chosen to meet the requirements of (i) being not limiting for evaporation and (ii) having a small height that enables reaching steady state quickly, air flow rate was fixed at ~3.7 L min^{-1}, and several ambient temperatures were chosen between 5 and 36 °C.

Results and discussion

The numerical results of the streamlines and velocity field inside a laboratory volatilization chamber depict a rather uniform velocity field, belonging in the laminar regime (Fig. 2).

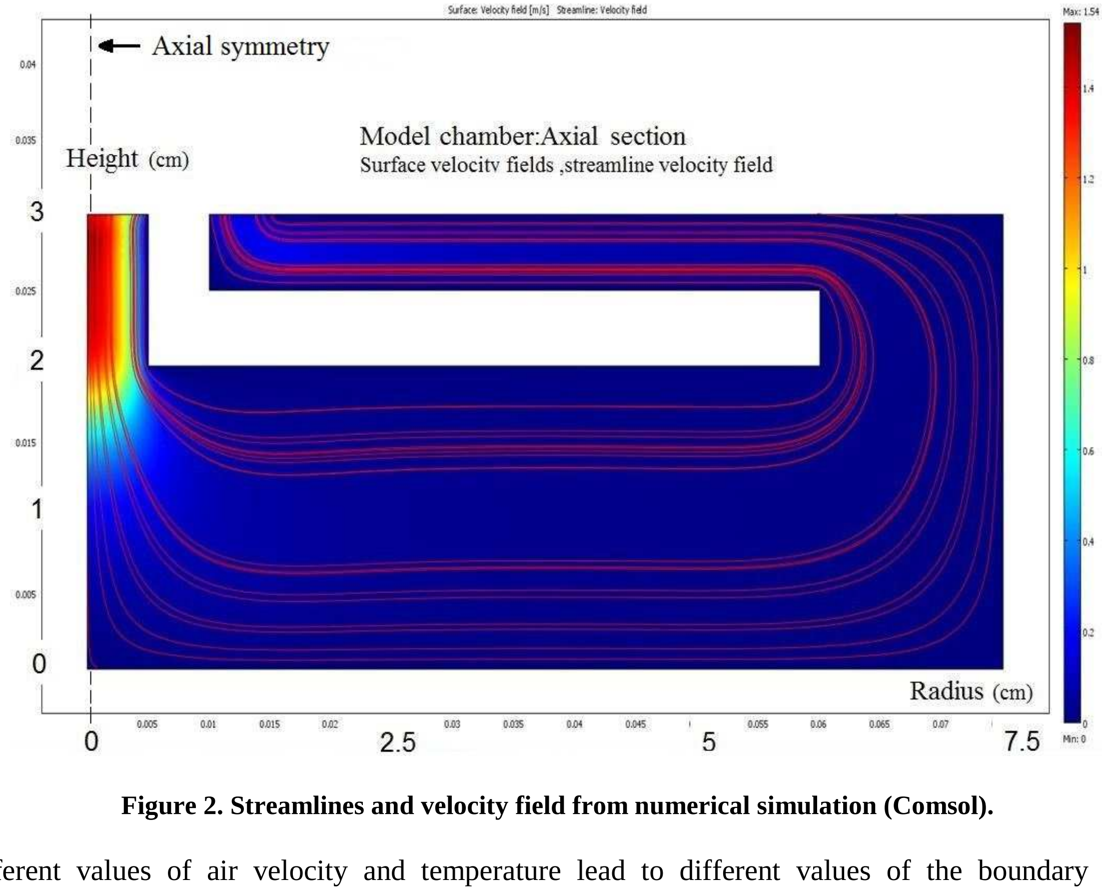
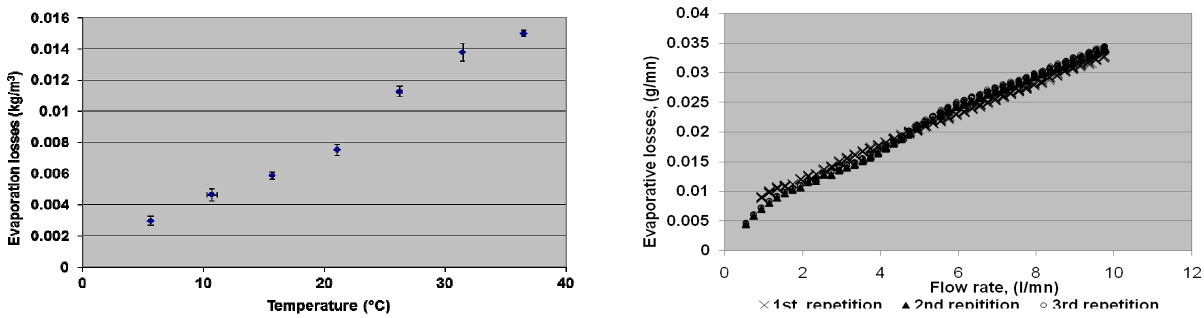


Figure 2. Streamlines and velocity field from numerical simulation (Comsol).

Different values of air velocity and temperature lead to different values of the boundary layer resistance (r_b) affecting the heat and latent fluxes in the chamber. Results are shown for latent fluxes in Fig. 3. More specifically, in Fig. 3a there is a linear relationship between temperature and evaporation flux. After three repetitions with the same flow rate increase (Fig. 3b), the evaporation losses are following also a linear increase leading to the conclusion that at these values of flow rate, the flow is more or less laminar. This is in agreement with the result of Fig. 2.



(a) (b)

Figure 3. Mass evaporation losses in the chamber as a function (a) of temperature for a constant air flow and (b) of airflow rate for constant temperature.

Conclusion and perspectives

The extrapolating tool may be used to generate "real" ammonia volatilization fluxes after manure application to arable land (i) in explored conditions from the wide spread wind-tunnel experiments reported in literature and (ii) in a large range of environmental conditions from laboratory experiments. They will be useful to provide France-specific emission factors for national emission inventories of atmospheric ammonia from agriculture.

After incorporating the extrapolation tool into the calculation of the volatilization rates, the first comparisons carried out in order to validate the extrapolation tool (not shown here) indicate that it still requires some further adjustments before it becomes an effective tool for calculating the ammonia emissions.

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