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Dosage-based parameters for characterization of puff dispersion results

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HIGHLIGHTS

- A consistent set of dosage-based parameters for puff dispersion characterization is introduced.
- The scalability and the validity of parameters are confirmed by systematic wind tunnel measurements.
- The effect of the release duration on the parameters is investigated.

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ABSTRACT

A set of parameters is introduced to characterize the dispersion of puff releases based on the measured dosage. These parameters are the dosage, peak concentration, arrival time, peak time, leaving time, ascent time, descent time and duration. Dimensionless numbers for the scaling of the parameters are derived from dimensional analysis. The dimensionless numbers are tested and confirmed based on a statistically representative wind tunnel dataset. The measurements were carried out in a 1:300 scale model of the Central Business District in Oklahoma City. Additionally, the effect of the release duration on the puff parameters is investigated.

1. Introduction

Emergency situations in urban environments often involve instantaneous or short-term releases (puffs) of airborne hazardous materials. The characterization of such scenarios is rather difficult due to the complex flow and dispersion phenomena within the urban canopy layer. Here the building structure has a strong impact on the flow field.

Despite the existence of widely used methods for dispersion estimation, there is no common practice on the characterization of puff dispersion. Books written four decades ago already describe the physics and modelling of puff dispersion (e.g. [1,2]). The Gaussian puff and plume models have been widely applied in the last 50 years for dispersion modelling [2,3]. It is a fast tool, practical in emergency situations. However, the assumptions behind the model might lead to difficulties in predicting the dispersion in an urban environment. Other generally used models are Lagrangian particle models (e.g. [4]) and computational fluid dynamics (e.g. [5,6]). Numerical models and measurements (in wind tunnels and in the field) are often carried out to predict and investigate puff dispersion. For the evaluation of the results mainly case-specific puff parameters are defined.

This paper offers a consistent set of parameters for puff dispersion characterization. The parameters are defined based on the dosage of the puff, providing a uniform, widely applicable criterion. Dimensionless numbers are introduced to convert the parameters from model scale to full scale. The scalability and the validity of the parameters are tested based on systematic wind tunnel measurements providing statistically representative data.

2. Literature review

In the atmosphere a puff is released into a turbulent flow field. Since turbulent flow is random at relevant dispersion scales, it

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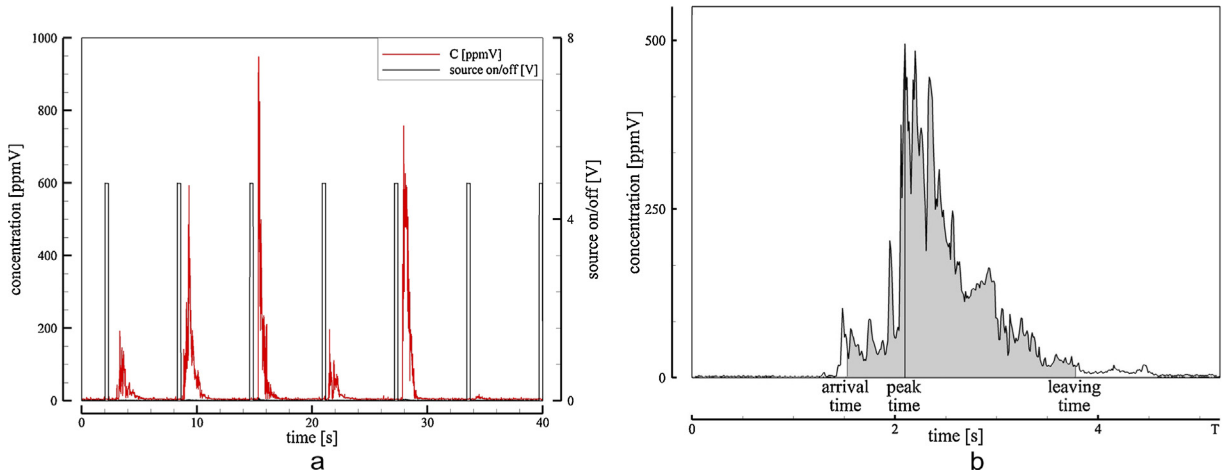

Fig. 1. Concentration time series of consecutively released puffs (a). A typical concentration time series during puff measurements (b). The dosage-based arrival time, peak time and leaving time are also indicated (based on Figs. 3 and 4 in [20]).

will cause the concentration field to be random as well. Consequently, concentration at a particular place and time is assumed to be unpredictable. Due to the turbulence, each realization of puff dispersion will be different from one another. A section of a typical concentration time series of consecutive puff releases is shown in Fig. 1a, demonstrating the variability of the results. Due to the randomness of the processes driving dispersion, Chatwin [7] suggested using Probability Density Functions (PDF) to characterize the variability of puff release dispersion. However, there is still no commonly applied practice on the physical characterization of puff release measurements. During puff dispersion measurements, concentration time series are recorded at defined locations. Based on the time trace, puff characteristics are derived. A typical puff signature taken from a corresponding time series can be seen in Fig. 1b. Typical parameters are the peak (or maximum) concentration, the dosage, the arrival (or travel) time, the peak time and the leaving (or departure) time. From these parameters, further characteristics can be derived, such as the puff advection speed and the duration (or puff retention time). However, the definition of the parameters listed above differs in the literature. Some examples of the different definitions of puff parameters are given by Zheng et al. [8].

The most common practice to define the characteristic times of a puff (such as arrival time, duration and leaving time) is to set an absolute threshold criterion. The puff is considered to be present at the measurement location, when the concentration is exceeding the chosen threshold. The most evident threshold is zero concentration [9]. This might be adequate for characterizing results from a numerical simulation representing an ideal scenario (e.g. [6,10]) or for spectral analysis [11]. For extreme value analysis, when the high concentrations are investigated using the generalized Pareto distribution, problems related to the uncertainty of the low concentrations can be avoided [12]. For toxic or flammable substances, the threshold might be chosen according to acute toxicity limits [13] or lower flammability limits [14]. However, these values are substance specific, with limited transferability to the gases generally used in field trials and wind tunnel measurements. Furthermore, these levels set the threshold rather high compared to the measured concentration. This results in significant wastage of valid data. Therefore, this method is mostly applicable for studies that investigate high concentrations (as in [13,14]).

The threshold used for the evaluation of measured puff data is usually set to a value higher than zero. This is due to the noise inherently present in almost all measured signals and the uncertainty of the measurement devices (including calibration uncertainty). Techniques involve setting an absolute threshold above zero (e.g. [15]) or applying some kind of baseline removal technique on measured time series (e.g. [16]). In case of a statistically representative dataset with a large number of puff measurements the variability of the results is high. This makes it extremely difficult to define an absolute threshold or a universal baseline, which is sufficient for each puff. (Further discussion on baseline removal techniques and the problems with applying an absolute threshold can be found in [17,18].)

Zhou and Hanna [9] present various approaches to derive the duration of a puff. One of the applied methods is to set the threshold relative to the peak concentration. This method allows defining the threshold independently for each puff. A similar approach was applied for the results of the wind tunnel measurements [19] connected to the DAPPLE field campaign [20]. Here the threshold was related to the 50% of the peak concentration.

The problem yet of using only a threshold criterion is that spikes (caused for example by dust particles entering the measurement volume) might appear in the concentration signal. Such a spike may be large enough to be considered as a valid signal by mistake [21]. Doran et al. [22] define the arrival time as the time after the release, when the concentration first exceeds and remains above an absolute threshold for a specified duration. This method solves the problem related to spikes in the signal. However, setting a minimum duration can also exclude highly intermittent signals, which occur often at measurements taken close to the source location.

The characterization method presented in this paper is based on the dosage of the measured puff. The dosage of the whole measurement signal is taken into account. The background concentration needs to be recorded and subtracted from the measured time series previously. The advantage of taking a defined portion of the dosage as the threshold for characteristic time measures is its cumulative nature. This ensures that spikes have a negligible effect on the puff parameters, while intermittent signals are still taken into account. This consistent definition of puff parameters sets a relative criterion, which can provide different absolute threshold values for each puff. However, the dosage-based criterion is not always the most appropriate to characterize puff dispersion. When the release duration is changing or the exceedence of an absolute threshold is investigated, choosing a threshold-based criterion might be more convenient. As an example, finding the duration, while the concentration is over an absolute threshold (such as exposure limit [13] or flammability limit [14]), the threshold-based criterion is more adequate.