Puff dispersion in a simplified central-European city

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ABSTRACT: Prevention and intervention in cases of hazardous gas releases in urban structures is substantially influenced by knowledge about transient dispersion processes in complex heterogeneous environments. Providing validation data for numerical dispersion models through extensive physical modeling enables those transient processes to be studied systematically. Especially the investigation of dispersion processes resulting from short time releases of pollutants provides numerous possibilities to describe systematic dependencies of dispersion phenomena. The paper describes an extensive set of systematic wind tunnel experiments focusing on puff dispersion in a simplified city structure called ‘Michelstadt’. A brief introduction of the experimental setup and the measurement strategy as well as selected results of a systematic analysis of the large set of data is presented.

1 INTRODUCTION

Modern developed industries depend on a large variety of potentially harmful substances. The usage and transport of those hazardous agents is not free of risks. Handling those substances in a dense settlement area and at logistic crossroads increases the risk of harming a large number of individuals and/or important infrastructure in case of accidents. Accidental or deliberate releases of harmful substances in urban structures pose a tremendous challenge for first responders and emergency response personnel. Within minutes after the release, first responders are forced to decide, how to deal with a usually very complex dispersion situation. Most of the decisions have to be made without knowledge about the released material, its chemical and environmental properties, without knowing in detail the driving weather conditions, or under which circumstances the actual release took place. The situation gets further complicated by the presence of complex heterogeneous city structures, significantly influencing the ground level winds. The large variability of those winds in the urban canopy layer causes a wide range of possible exposure values and travel times of pollutants to characterize the dispersion in a specific case. Computational dispersion models implemented in decision support systems can provide a qualified option to assist first responders. Those models largely differ regarding their complexity and structure and dispersion simulations can result in completely different predictions depending on the type of dispersion model applied. Up to now, there are only a few field and laboratory sets available, dealing with the variability of short time releases in complex terrain, which could be used for validating corresponding
dispersion models. In order to initiate systematic studies, to improve the understanding of transient dispersion processes and to possibly provide qualified and detailed reference data for the validation and improvement of applied and scientific numerical puff dispersion modeling, a systematic series of transient dispersion experiments was carried out in a simplified urban structure in the atmospheric boundary layer tunnel ‘WOTAN. In the addition to the work presented by Harms et al (2013), dealing with the specifics of hazmat dispersion model validation, and the work presented by Berbekar et al (2013), focusing on the specifics of quality assurance for validation data, this paper, is concentrating on the characteristics of instantaneous gas releases and a possible characterization of dispersion parameters.

2 EXPERIMENTAL SETUP

The measurements have been conducted in the atmospheric boundary layer wind tunnel WOTAN using a 1:225 scale model of a semi-idealized urban structure. The experimental facility and the model setup for the experiments and the urban structure of Michelstadt is explained in Harms et al (2013). During a first experimental campaign, measurements have been accomplished by Berbekar for one wind direction. In order to generate an additional set of systematic data, the model was turned around by 180 degrees for the measurements presented here. Approach inflow conditions were kept the same as for the preceding measurements. As indicated by the square symbols in Figure 1, four sources have been placed in the modeled city structure. To compare different release conditions, the source location was varied between an inner yard source and street canyon sources with different orientation, resembling undisturbed approach flow conditions for a street canyon aligned with the mean wind and blocked inflow conditions for streets behind apartment blocks oriented nearly perpendicular to the above roof mean wind direction.

![Figure 1 Urban structure with 4 source locations as squares and measurement points for source 5 as crosses.](image-url)
Based on the results of systematic continuous release measurements (Harms, 2013), a number of representative measurement locations was defined for each of the source positions tested. To consider a variety of possible parameters of instantaneous dispersion phenomena intended to be investigated, measurement points have been placed at different distances to the source, inside and outside of inner yard structures or in the center as well as the outer edge of the area affected by previously measured continuous release plumes. Furthermore, the varying street canyons enabled measurement points to be placed in streets with substantially different flow conditions. Figure 1 shows, as example, the measurement locations for releases from source 5.

3 PUFF DISPERSION MEASUREMENT

A puff release of hazardous material is defined by the release duration. Whether or not a dispersion scenario might be called transient or puff-like depends on the time duration, the material needs to travel from the source to the measurement point. To realize puff-like discharges, the release time for the sources was set to 0.3 s at model time scale during the measurements. Thus, travel time of the gas cloud or puff is significantly larger than the release time. The concentration time traces of the trace gas have been measured with a Fast Flame Ionization Detector providing a frequency response of about 140 Hz. In order to describe the puff characteristics properly, a sufficiently large number of individual puff releases was sampled for each source/receptor configuration for the same mean wind and release conditions.

![Figure 2: Typical concentration measurement signal with seven consecutive puff releases during one measurement, separated by the source trigger signal.](image)

Experimentally verified quasi-stationary mean boundary conditions are necessary to collect data ensembles large enough to form a statistically representative group of individual releases. The heterogeneous urban structure and the highly turbulent boundary layer flow result in a
large variability of the individual concentration signals recorded. The significant differences in the measured concentration signals for just one source/receptor configuration are shown in Figure 2. The rectangular vertical bars indicate the trace gas release over the time period of 0.3s. The curve shows the varying puff concentration-time trace, for a number of individual puff releases. For two of the releases shown, a rather small peak concentration is observed. This is suggesting, that the released clouds almost missed the measurement location, whereas other puffs show significantly higher concentration levels and, as expected, a large variability in shape of individual concentration time traces. Although a ‘mean puff’ can be defined from a reasonable amount of releases, the ‘mean puff’ itself is not describing the variability inherently present in the puff signals recorded. Thus, further analysis is based on a number of puff parameters such as arrival time (at), peak time (pt), peak concentration (pc), leaving time (lt), duration (lt-at) or dosage (dos). Each parameter can be ascertained for each individual puff signal. Arrival time and leaving time interval are a defined by means of a dosage-based-criterion if 5% and 95% of the total dosage of a puff have been reached. Unlike a certain threshold criterion, the dosage based criteria delivers reliable result for arrival and leaving time nearly independent from the actual concentration levels measured. Further descriptions are given in Harms (2011). It is also mentioned that, for a different urban structure, an ensemble of more than 200 puffs enabled the mean puff parameters to be calculated within an uncertainty of about ± 5%. Hence, in the present study at least 200 individual puff releases were recorded for each source/receptor configuration.

4 SELECTED RESULTS

The main objective of the study was, to find systematic dependencies of the mean puff parameters from corresponding release and dispersion conditions. Before an in-depth analysis, all measured data were made dimensionless to make them comparable. During a careful quality check of the data by Berbeka et al (2013), puff signals containing potentially erroneous data have been excluded from further analysis. For the first break down of results, puffs were sorted by location. Two categories were defined; the first is sorting the measurement points by distance from the source in full scale dimension and defining two characteristic dispersion areas as periphery and center of the exposed area. A measurement location was considered to be in the center of the continuous release plume, if more than 95% of the released puffs reached the measurement site. An exception had to be made for measurement locations within closed courtyards because of their specific ventilation behavior. As a second sorting criterion the pure location of a measurement point in a street canyon aligned or inclined to the mean wind direction or in inner courtyards was chosen. Figure 3 shows the results for the mean puff arrival time sorted by both criteria. As expected, the arrival time increases with increasing distance from the source. It can be seen that with increasing distance, the increase of the arrival time slows down. Compared to the street canyon locations the general increase in arrival time seems to be smaller if the measurement point is located within an inner yard. However, the still relatively small number of measurement points for each type of receptor location prevents more quantitative conclusions.
Figure 3: Mean non-dimensional arrival time (at) as a function of distance and sorted by location

Figure 4: Mean non-dimensionless peak concentration (pt) as function of source-receptor distance measurement location
Similarly, the measured peak concentration can be analyzed. As expected, the mean peak concentration decreases with increasing distance from the source. This behavior is found for all tested source/receptor configurations but it differs again for the inner yard locations. Corresponding results are summarized in Figure 4. In addition to the exemplary results presented here, all other mean puff dispersion parameters were analyzed systematically regarding possible systematic dependencies. Furthermore, a methodical analysis of individual puff data ensembles was carried out in order to evaluate frequency distributions of transient dispersion parameters and to estimate extreme values as they are of particular interest for threat assessment in the context of dispersion of hazardous materials.

5 CONCLUSION

Transient dispersion phenomena, resulting from puff-like releases in a complex urban geometry, were modeled and measured in a boundary layer wind tunnel. A methodical analysis of measurement results reveals systematic dependencies of transient dispersion parameters from both, geometrical and physical boundary conditions. The extensive set of experimental data enables a statistically representative fundamental relationship to be derived, not only for mean puff dispersion parameters but also for extreme values, which are of particular interest for practical implementations in the context of emergency response during local-scale hazmat releases in urban areas.

6 REFERENCES

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