Journal of Hazardous Materials 300 (2015) 182–188

Contents lists available at ScienceDirect

Journal of Hazardous Materials

journal homepage: www.elsevier.com/locate/jhazmat

Modelling short term individual exposure from airborne hazardous releases in urban environments

J.G. Bartzis[a,*], G.C. Efthimiou[b], S. Andronopoulos[b]

[a] University of Western Macedonia, Dept. of Mechanical Engineering, Sialvera & Bakola Str., 50100, Kozani, Greece
[b] Environmental Research Laboratory, INRASTES, NCSR Demokritos, Patriarchou Grigoriou & Neapoleos Str., 15310, Aghia Paraskevi, Greece

HIGHLIGHTS

- The statistical behavior of the variability of individual exposure is described with a beta function.
- The extreme value in the beta function is properly addressed by [5] correlation.
- Two different datasets gave clear support to the proposed novel theory and its hypotheses.

ARTICLE INFO

Article history:
Received 3 April 2015
Received in revised form 22 June 2015
Accepted 23 June 2015
Available online 27 June 2015

Keywords:
Individual exposure
Extreme concentrations
Beta distribution
Concentration fluctuations
Concentration statistics

ABSTRACT

A key issue, in order to be able to cope with deliberate or accidental atmospheric releases of hazardous substances, is the ability to reliably predict the individual exposure downstream the source. In many situations, the release time and/or the health relevant exposure time is short compared to mean concentration time scales. In such a case, a significant scatter of exposure levels is expected due to the stochastic nature of turbulence. The problem becomes even more complex when dispersion occurs over urban environments. The present work is the first attempt to approximate on generic terms, the statistical behavior of the abovementioned variability with a beta distribution probability density function (beta-pdf) which has proved to be quite successful. The important issue of the extreme concentration value in beta-pdf seems to be properly addressed by the [5] correlation in which global values of its associated constants are proposed. Two substantially different datasets, the wind tunnel Michelstadt experiment and the field Mock Urban Setting Trial (MUST) experiment gave clear support to the proposed novel theory and its hypotheses. In addition, the present work can be considered as basis for further investigation and model refinements.

1. Introduction

Increasing urbanization and the resulting localization of human living and industrial production within relatively small areas lead to very demanding standards for human safety and air quality in urban environments. In this context there is a necessity to be able to cope with deliberate or accidental atmospheric releases of hazardous chemical, radioactive or bacteriological substances that might happen within urban and industrial areas in order to minimize or even eliminate the resultant potential health hazard. The basis of efficient emergency management is the ability to reliably predict the individual exposure downstream the source.

In quantitative terms the fundamental parameter characterizing the individual exposure within Δt to a certain receptor downstream the plume is the time averaged concentration within $\Delta\tau$ defined as:

$$C(\Delta\tau) = \frac{1}{\Delta\tau}\int_{\Delta\tau} c(t)dt \tag{1}$$

where $c(t)$ is the instantaneous concentration at the receptor point and $\Delta\tau$ is the exposure time considered.

The relevant duration of the exposure time $\Delta\tau$ is selected either on health impact considerations or on the hazardous substance release duration or on real conditions (e.g., the time an individual is expected to stay at the particular location). Especially near the emission source there might be cases where the concentrations are very high and related time scales are as low as breathing time (i.e., a few seconds). On the other hand very short releases in the order

* Corresponding author. Fax: +30 24610 56716.
E-mail address: bartzis@uowm.gr (J.G. Bartzis).

http://dx.doi.org/10.1016/j.jhazmat.2015.06.057
0304-3894/

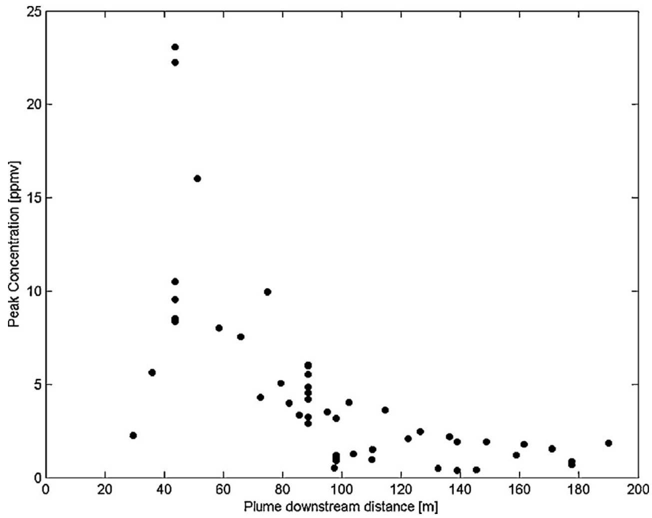

Fig. 1. Peak experimental concentration as function of downstream distance for Trial No 11 of the Mock Urban Setting Trial (MUST) experiment [23].

of a few seconds up to a few minutes are common scenarios for the above mentioned accidental or deliberate release events.

Thus, the prediction of short time exposure at the receptor of interest is often a fundamental necessity when dealing with critical safety and security problems.

The atmospheric dispersion in complex environments such as the urban ones is a complex problem. The need however for short time exposure prediction makes the problem even more difficult if one takes into consideration that local airborne hazardous substance concentration is a highly variable parameter due to the stochastic nature of turbulence. A practical consequence of this stochastic behavior of pollutant concentration values in urban environments is the highly intermittent characteristics of the concentration time series. Enhanced by the street network, natural variability of urban wind conditions due to local turbulence is leading to quite different plume pathways for different time of releases [16].

In other words how the plume is going to be dispersed depends on what the local instantaneous atmospheric initial conditions at the time of the release are. However, those conditions are not possible to be defined completely in a physical sense. On realistic terms what can be best expected, is the possibility at the receptor point to be able to predict at a given time interval $\Delta\tau$ the maximum expected concentration $C_{max}(\Delta\tau)$ and even the set of the values that the actual concentration $C(\Delta\tau)$ can take in terms of a probability density function (pdf).

The common methodology today to predict maximum concentrations is the utilization of well-established probability density functions (pdf) (e.g. chopped normal, log-normal, gamma or Weibull) for the concentration distributions [18,22,24,14,13]. In this case, a computational dispersion model uses the predicted concentration mean, variance and intermittency factor and a predefined probability density function as mentioned above, to estimate the peak concentration with a confidence interval (e.g., 95% or 99%). For example, the widely used puff model SCIPUFF [21] uses the chopped normal distribution.

It is noticed that the results are expected to be sensitive to the particular pdf and especially on the confidence limit selected. Therefore additional criteria are needed to specify the appropriate confidence interval level [12]. In reality the maximum concentrations are real deterministic numbers and are expected to dilute downstream. As illustrated in Fig. 1, the $C_{max}(\Delta\tau)$ measured during the Mock Urban Setting Trial (MUST) experiment Trial No 11 [23] is plotted against plume downwind distance. The dilution of $C_{max}(\Delta\tau)$ as the pollutant moves downstream is clear.

Thus, there is a necessity to seek for a new pdf for $C(\Delta\tau)$ in which not only the mean and variance are the defining parameters but also the extreme value $C_{max}(\Delta\tau)$. The derivation of a new pdf for $C(\Delta\tau)$ and the associated maximum expected concentration $C_{max}(\Delta\tau)$ will be the main effort under the present investigation.

This new knowledge could be further exploited especially in emergency management for (a) enhancing atmospheric dispersion modeling relevant capability and (b) providing methodology on extreme value predictions of online monitoring sensor time signals during a release event.

In the present work, it is assumed for simplicity, that the release rate is continuous and constant. The source is near the ground and pollutant is dispersed through a complex environment (e.g., urban). It is noticed that a solid methodology appropriate for this kind of problems could serve as a basis for other types of releases such as instantaneous and/or finite time.

2. The present approach

Adopting any finite range pdf for $C(\Delta\tau)$, the prerequisite is the ability to estimate the extreme value $C_{\max}(\Delta\tau)$. For this purpose, the following approach introduced by [5] is used as a basis:

$$\eta = \frac{C_{\max}(\Delta\tau) - \bar{C}}{\bar{C}} = b \times \left(\frac{\Delta\tau}{T_c}\right)^{-\nu} \times I \qquad (2)$$

where $\bar{C}$ the mean concentration, σ_C^2 the concentration variance and I is the concentration fluctuation intensity.

$$I = \frac{\sigma_C^2}{\bar{C}^2}, \sigma_C^2 = \bar{C'^2} \text{and} T_C = \int_0^\infty R_C(\tau)d\tau \qquad (3)$$

C' are the concentration fluctuations, T_C is the concentration integral time scale derived from the concentration autocorrelation function $R_C(\tau)$.

The parameters b and ν are derived from experimental evidence. It is noticed that the calculated b and ν values among the various receptors in a specific release exhibit variability reflecting above all, the model imperfectness, the experimental errors, the insufficient degree of the signal stationarity and the signal finite duration. Looking for indicative values for $C_{\max}(\Delta\tau)$,

best fit analysis of field experimental data such as MUST [23] and FLADIS [20] have suggested the values $b = 1.65$ and $\nu = 0.3$ [3]. The so obtained relationship [2] has been used by the authors in the past, to predict successfully maximum concentrations from near ground releases using Computational Fluid Dynamics (CFD) methodology for $\bar{C}$ and σ_C^2 prediction by solving the relevant transport equations [9,8,10,11].

However, in the present approach, since we are looking for the pdf upper bound at a certain receptor, we are going beyond the abovementioned indicative maximum value and we are focusing on the extreme value $C_{\max}(\Delta\tau)$ in the hypothetical case that a pollutant release lasts for an infinite time. It is noticed that such an extreme value cannot be quantified experimentally since no experiment can run for infinite time which is not realistically possible. In a specific receptor in which the concentration time series is measured, when comparing the measured peak value $C_{\max}^{\text{meas}}(\Delta\tau)$ with the expected extreme value $C_{\max}(\Delta\tau)$, it is always $C_{\max}^{\text{meas}}(\Delta\tau) \le C_{\max}(\Delta\tau)$. This is due to the fact that the measured peak value is obtained from a time series of finite duration since infinite experimental time is not possible.

The proposal here is that this extreme value $C_{\max}(\Delta\tau)$ is also provided by Eq. (2) with new values of the parameters b and ν. The adopted strategy here is to fix the value of $\nu = 0.3$ and allow the b