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Relation of puff and continuous dispersion within urban canopy

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Abstract: Protection of inhabitants of densely populated urban areas is a very important topic. Residents can be threatened by accidental releases of toxic gases. These releases can occur e.g. from a factory working with chemicals, a vessel transporting chemicals, or by an intentional attack. Most of such releases have duration of few minutes to one hour. This leads to dispersion pattern called puff. Due to stochastic nature of turbulence of the atmospheric flow the prediction of puff dispersion is possible only in statistical sense.
The presented paper will introduce dispersion experiments of both puff and continuous releases within an urban canopy. The experiments were conducted at the environmental wind tunnel of the Institute of Themomechanics. The model of an idealised urban canopy representing typical European architecture consisting of rectangular blocks of buildings with pitched roofs and inner courtyards was manufactured in the scale 1:400. A point source of tracer gas was mounted at the ground level. Flow and dispersion was measured by time resolving instruments (Laser Doppler Anemometry and Flame Ionisation Detector, respectively).
At each point concentration time series from continuous and puff (i.e. ensembles of puff realisations) releases were recorded. Characteristics of the puff case as well as the continuous case were calculated. Linear relationship between mean concentrations in the continuous case and mean 99%, as well as mean 95% quantile of concentrations in the puff case within separate traverse streets in view of flow is perceptible from the results.
Assessment of puff ensemble characteristics by continuous dispersion characteristics is highly valuable, since many numerical models calculate only with Reynolds averaged equations and they are able to predict only statistics of continuous dispersion.

Key words: *atmospheric boundary layer, pollution dispersion, instantaneous release, wind tunnel*.

INTRODUCTION

The air pollution studies are mostly concerned with long lasting gas sources (e.g. car exhausts, factory stacks). But the reality after a gas leakage accident is usually very different. The amount of released gas is finite; leakage lasts for a relatively short time. For risk assessment the duration of a gas leakage is an important factor. While in cases of continuous gas source the measured concentration amount can be neglectable, it does not have to be true in the short duration one.
During the instantaneous leakage a gas cloud is created and it is then transported and dispersed by wind. Because gas leakage duration is shorter in comparison with the average time for turbulent wind, the runs of individual gas releases differs from replica to replica. In the one replica a cloud in a certain place after a sudden release of gas can be seen as an increase of a concentration of a released substance, its abidance in that place and then its more or less slowly concentration decrease, in the other replica the cloud can be split in two or more parts. Sometimes a gas leakage does not have to be even observable in the given place.
Conducting many repetitions of the short duration gas leakage, a statistic representative dataset can be obtained. The number of repetitions chosen by experimenters differs. The most common ensemble largeness in literature is 50 to 100 repetitions (e.g. (Sweatman & Chatwin, 1996), (Meroney & Lohmeyer, 1984)). However, more recently the repetitions number is usually higher. According to (Harms, Leitl, & Patnaik, 2011) or (Lübcke, Harms, Berbekar, & Leitl, 2013) about 200 puff experiment realisations is

needed for obtain the statistically representative dataset of the concentration measurements in idealised model called “Michelstadt”, on the contrary (Mei, Leitl, Fischer, & Schatzmann, 2009) suggests that even more than 300 repetitions are necessary for finding the linear relationship between the puff characteristic called dosage and duration of gas leakage at the sampler place.

The characteristics of puffs - as the time when gas cloud attaches the given place, its duration, maximum expected concentration or concentration dosage measured in different places – can help emergency services (e.g. fire fighters, doctors) estimate the threat in different locations after a sudden release of gas. These ensembles mean puff features can be then compared with continuous gas sources. Because the mathematic models used to predict the situation after a gas leakage use usually Reynolds equations, they can predict only mean concentration. Therefore it is important to study the differences between continuous and puff cases. This paper compares dispersion after a short lasting gas leakage and a long duration one from ground level point gas source in an idealised urban area. It will be equated mean maximum, mean 99% and mean 95% quantile of concentrations of puff releases with mean concentrations measured in case of continuous gas sources. Linear relationship between mean concentrations in the continuous case of source and mean 99%, as well as mean 95% quantile of concentrations in the puff source case within separate traverse streets in view of flow is perceptible from the results.

EXPERIMENTAL SET-UP

Wind tunnel

The experiments examining processes of puff as well as continuous case dispersion in urban areas were carried out in the Laboratory of Environmental Aerodynamics of the Institute of Thermomechanics AS CR in Nový Knín. The scheme of the low speed wind tunnel is displayed in Figure 1. The test section of the tunnel is 2 m long; its cross-dimensions are 1.5 m × 1.5 m. The wind tunnel parameters are more detailed described in (Jaňour, 2001). The turbulent boundary layer is developed using spires and roughness elements in the tunnel (see Figure 2).

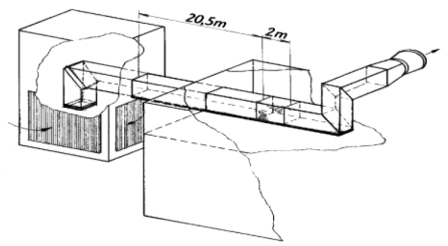


Figure 1. Wind tunnel of the Institute of Thermomechanics.

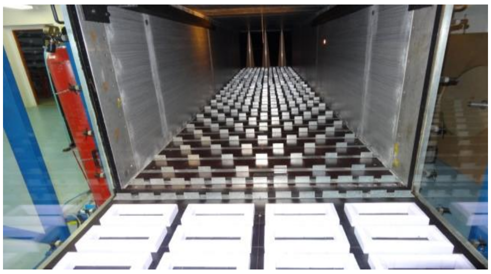


Figure 2. Development of the boundary layer in the tunnel.

Model

In experiments we used a model of an idealised urban canopy representing typical European architecture in inner parts of cities. This model consists of rectangular blocks of buildings with pitched roofs and inner courtyards (see Figure 3).The manufacture scale is 1:400. Buildings are 63 mm high (50 mm body of the building with 13 mm pitched roof) and 37.5 mm width. Courtyard dimensions are 150 mm × 300 mm. These courtyards are placed 50 mm from each other.

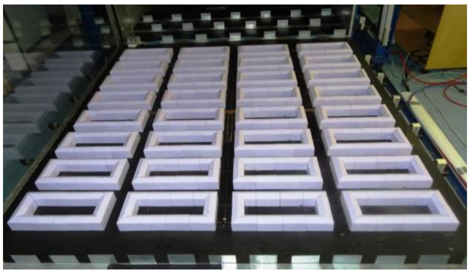


Figure 3. Model representing idealised inner parts of European cities.

Gas source
We placed a ground level point gas source into the model in the wind tunnel. It was simulated by a pipe with inner diameter 8 mm, outer diameter 10 mm. We used ethane as a passive tracer in our experiments.

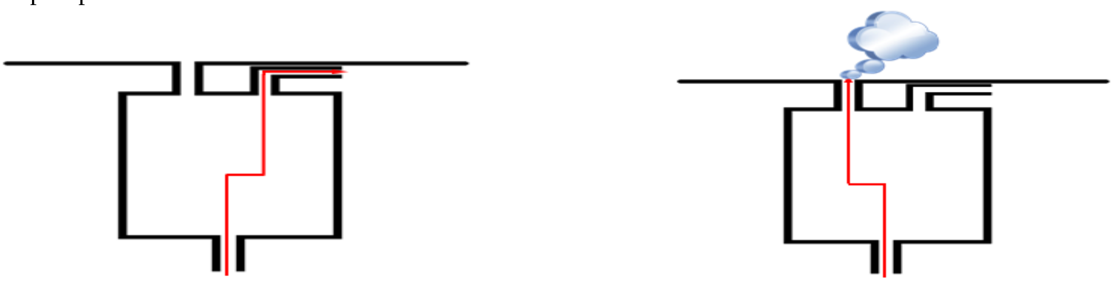
The principle of puff creation

Short duration releases were produced by Programmable Logic Controller (PLC) Siemens LOGO! 12/24 RCE 0BA 7 and electromagnetic 3/2 valve ND5 of Norgren (see Figure 4).

a b

Figure 4. Equipment for puff creation – PLC Siemens LOGO! (a) and electromagnetic valve of Norgren (b).

The principle of puff creation in the testing section inside the tunnel is depicted in Figure 5. The gas is transported in the hose to the bottom orifice of the electromagnetic valve. Then there are two options (two orifices) where gas can flow depending on the valve state (without voltage or under voltage created by PLC).
During the interval when the electromagnetic valve is not under voltage, gas flows through the orifice that empties to the area out of the testing section of the tunnel with the model (the right one in Figure 5a).
During the interval when the electromagnetic valve is under voltage (created by PLC), gas flows through the orifice that empties into the testing section (the left one in Figure 5b) of the wind tunnel with the model. By this process a gas cloud is created in the tunnel. Duration of gas leakage simulating puffs was 1 s in the model scale in our experiments. We conducted about 400 experiment realisations at each sampler place.



a b

Figure 5. Principle of puff creation in the tunnel – valve without voltage (a) and under voltage (b).

Equipment for concentration measurement
It was used Laser Doppler Anemometry for flow measurements. Concentrations of gas tracer were measured by Fast Flame Ionisation Detector (FFID). The ends of FFID needles that sucked in mixture of air and ethane were placed to the height of 4 mm above tunnel bottom (1.6 m in full scale).

PHYSICAL QUANTITIES
In this article we will use dimensionless quantities. Dimensionless coordinates x and y are defined as

$$x^* = \frac{x}{H}, y^* = \frac{y}{H}. \tag{1}$$

Dimensionless concentration for point gas source is defined by the relation

$$C^* = \frac{C U_{ref} H^2}{Q} . \qquad (2)$$

In these relations U_{ref} stands for reference speed measured at height 2H above the tunnel bottom, H characteristic length (in this experiment buildings height 63 mm), C measured concentration, Q source intensity.

RESULTS

In Figure 6 there is depicted the investigated section of the model. Source location is drown by a black cross, places where the concentration measurements took place by red filled circles. Flow is parallel with the axis x*.

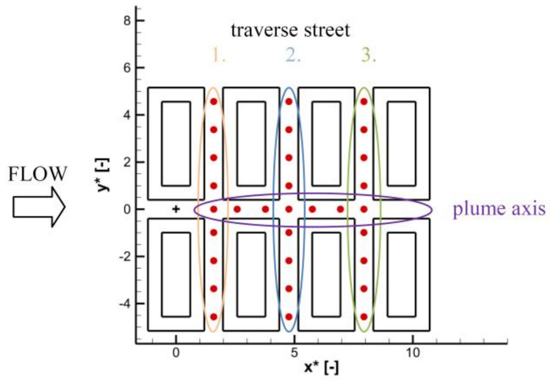


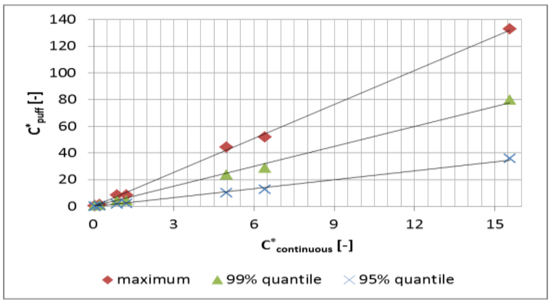
Figure 6. Scheme of investigated section (the source position is denoted as a black cross; red filled circles represent sampler places).

In this paper we will concern on the comparison of mean dimensionless concentrations C* measured in the case of continuous source and mean maximum, mean 99% quantile and mean 95% quantile of dimensionless concentrations C* in the puff source. Concentrations measured by FFID are very sensitive to the impurity sucked into the cramped needle. Therefore the maximum concentration as the quantity based on the measurement of only one value is more sensitive to this than mean 99% quantile or mean 95% quantile of concentrations.

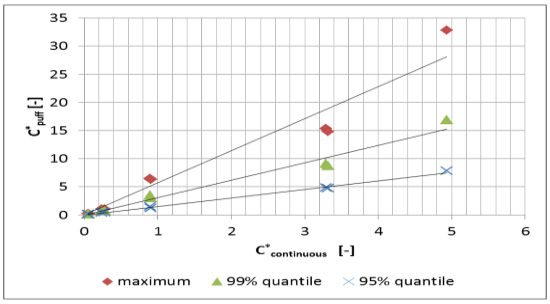
The measured concentrations decrease with the growing distance from the gas source in both, the continuous and the puff case. Figures 7a, 7b and 7c show results along the first, the second and the third traverse street. Linear relationship between mean dimensionless concentrations in the continuous case and mean 99%, as well as mean 95% quantile of dimensionless concentrations in the puff case is perceptible from these Figures. Linear relationship may be also between mean dimensionless concentrations in the continuous case and mean maximum dimensionless concentrations in the puff case. Mean maximum dimensionless concentrations evince larger values of residuals within traverse streets (especially within the second traverse street – see Figure 7b) in comparison with mean 99% and mean 95% quantile of concentrations. It is apparently because this quantity depends on only one measured concentration value within the concentration time series. Therefore it does not represent quantity general behaviour as much as concentration quantiles.

The slope of the regression line differs in the particular cases. Its value decreases from the first to the third traverse streets in the case of mean maximum dimensionless concentrations and mean 99% quantile of dimensionless concentrations. In mean 95% quantile of dimensionless concentrations the slope of the regression line decreases between the first and the second traverse street. But it does not decreases between the second and the third traverse street. The difference between slopes of regression lines of mean maximum, mean 99% and mean 95% quantile of dimensionless concentrations decreases from the first to the third traverse street. The reason is probably decrease of measured concentration values from the first to the third traverse street.

Along the plume axis, the relationship between mean dimensionless concentrations in the continuous case and mean 99% and mean 95% quantile of dimensionless concentrations in the puff case does not tend to be linear in the whole value range (see Figure 7d). The trend might become linear from higher measured concentration. More sampler places within the plume axis would be necessary for determination. This trend is not perceptible from the relation of mean dimensionless concentrations in the continuous case and mean maximum of dimensionless concentrations in the puff case measured within the plume axis. The probably reason of this behaviour is the feature of this quantity discussed above.



a



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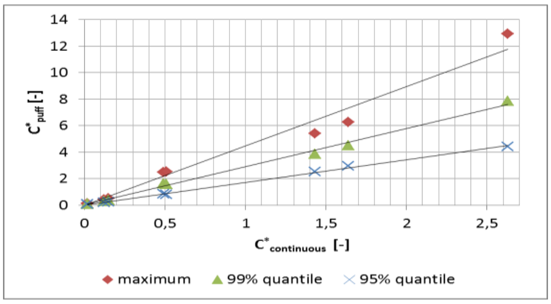

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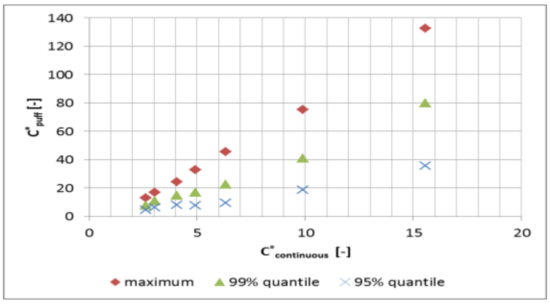

d

Figure 7. Relationship between mean dimensionless concentration for continuous source and mean maximum, mean 99% and mean 95% quantile of dimensionless concentrations for puff source within separate traverse streets (a corresponds to the first, b to the second, c to the third traverse street) and within the plume axis (d).

CONCLUSION

Paper compares concentration values within an urban area typical for European town inner-parts in case of continuous and short duration ground level point gas source. Results show linear relationship between mean concentration values for the continuous gas source and mean 99%, as well as mean 95% quantile of concentrations in the case of puff source within separate traverse streets in view of flow. Linear relationship may be also between mean concentrations in the continuous case and mean maximum concentrations in the puff case within separate traverse streets. Mean maximum concentrations evince in comparison with mean 99% and mean 95% quantile of concentrations larger values of residuals within traverse streets. It is apparently because this quantity depends on only one measured concentration value within the concentration time series.

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