AIR POLLUTION DISPERSION INSIDE A STREET CANYON OF GÖTTINGER STRASSE (HANNOVER, GERMANY) – NEW RESULTS OF THE ANALYSIS OF FULL SCALE DATA

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INTRODUCTION

In numerical modelling of street canyon pollution, an inverse proportionality between street level concentration and wind speed (U) measured above roof is commonly assumed. It is argued that in many instances (particularly when U is greater than 2-3 m s^{-1}) street ventilation is controlled by the interaction between the micro-scale flow structures and the urban boundary layer flow above roof level. In these situations, both buoyancy-related and traffic-produced turbulence (TPT) are considered secondary street-ventilation mechanisms compared to the main wind-induced mechanism. In this way, considering the specific emission per length (E) and the width (W) of the canyon, the normalised concentration (C*) (the background concentration, C_b, has been subtracted from the values of pollutant concentrations measured inside the street, C_i) would be (*Kastner-Klein, P. et al.*, 2003):

$$C^* = (C_i - C_b) W/E \propto U^{-1} \qquad (1)$$

This scaling concept produces significant reduction in modelling efforts in operational air quality studies. However, field data analyses have often demonstrated that the above scaling has certain deficiencies (*Ketzel M. et al.*, 2002, *Kastner-Klein, P. et al.*, 2003), since particularly with lower wind velocities TPT effects start to play an important role. For regulatory purposes, and empirical method (*VDI*, 1998) has been proposed to account for TPT effect, recommending to use $U^{-0.35}$ as velocity scale in equation (1) for situations with wind velocities smaller than 3.0m/s. *Ketzel M. et al.* (2002) analysed the application of a modified form of equation (1) given by: $C^* \propto U^{-\alpha}$. For the windward situation they found that α seems to be even higher than 1.

Different authors (*Kastner-Klein, P. et al.*, 2000, 2001, 2003; *Berkowicz R. et al.*, 2002; *Di Sabatino S. et al.*, 2003) studied the influence of turbulence created by traffic flow in the street, on air pollutant dispersion inside street canyons. *Kastner-Klein P. et al.* (2000, 2003) proposed that the turbulent mechanical motions related to wind and vehicle are mixed inside the canyon so that the effective velocity variance can be taken proportional to the linear combination between of the squares of roof wind speed (U) and vehicles velocity (V). They introduced the following expression for the dispersive velocity scale (u_s):

$$u_s = (\sigma_u^2 + \sigma_v^2)^{1/2} = (aU^2 + bV^2)^{1/2} \qquad (2)$$

where σ_u^2 is the wind speed variance, σ_v^2 is the traffic-induced velocity variance, a is a dimensionless empirical parameter that depends, among other factors, on street geometry, wind direction and sampling position and b is a dimensionless empirical parameter that is function of wind direction, vehicles characteristics, their drag coefficient and traffic density (N/V). For congested traffic b does not depend on traffic density (*Di Sabatino et al*, 2003). For leeward conditions, the normalised concentrations verifies the relationship $C^* \propto (u_s)^{-1}$. In a previous paper (*Mazzeo, N. and L. Venegas*, 2005) we obtained empirical expressions for the variation of a and b with wind direction and traffic density (N/V) for situations close to leeward conditions.

In this work we consider that
- for windward conditions, $C^*=(a^{1/2}U)^{-1}$ and an alternative $C^*=(A^{1/2}U^{\alpha})^{-1}$,
- for leeward conditions, $C^*=(aU^2+bV^2)^{-1/2}$

so the main objective is to study the behaviour of parameters a, b, A and α included in the previous relationships, considering all wind directions and using CO and NO_x concentrations, meteorological parameters and traffic flow measured continuously during 1994 in a street canyon of Göttinger Strasse (Hannover, Germany). We also study the variation of the critical wind speed (U_c) (that verifies $aU_c^2=bV^2$) with traffic density and wind direction.

DATA

Traffic pollution measurements in Göttinger Strasse (Hannover, Germany) have provided one of the most comprehensive datasets of airflow and pollution parameters in a typical urban street canyon. Air quality measurements for CO and NO_x have been obtained by a monitoring station located in this street canyon with a traffic volume of approximately 30000 vehicles per day (*N.L.Ö.*, 2000). Automatic traffic counts provide the vehicle flow in the street. Ambient wind direction and speed data are taken at a 10m mast on top of a nearby building. The background concentration samplers are also located on the roof of this building. The aspect ratio (H/W) of this canyon is 0.8.

RESULTS AND DISCUSSION

Normalised concentrations, C*, have been obtained considering emissions (E) calculated based on the number of vehicles (N_i) per hour in a class i (e.g. short, long) and emission factor (e_i) for vehicles in class i (*EMEP/CORINAIR*, 2004), as $E(g\,s^{-1}\,m^{-1})=\sum_i N_i e_i$.

We define θ as the direction of roof level wind referred to the street canyon orientation so that θ=0° when wind direction is 163° (Figure 1) Data have been grouped into "leeward cases" if $0° \le \theta \le 180°$ and "windward cases" if $180° < \theta < 360°$. The analysis has been done using statistical methods to obtain the best fits to measurements.

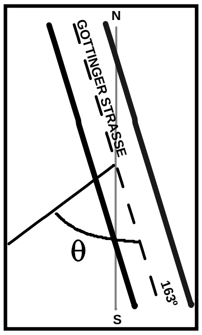

Fig. 1; Definition of θ

a) Analysis of "windward cases" data (180°<θ<360°)

Figure 2 shows, as an example, the variation of C* vs. U when θ = 270°, for CO and NO_x.

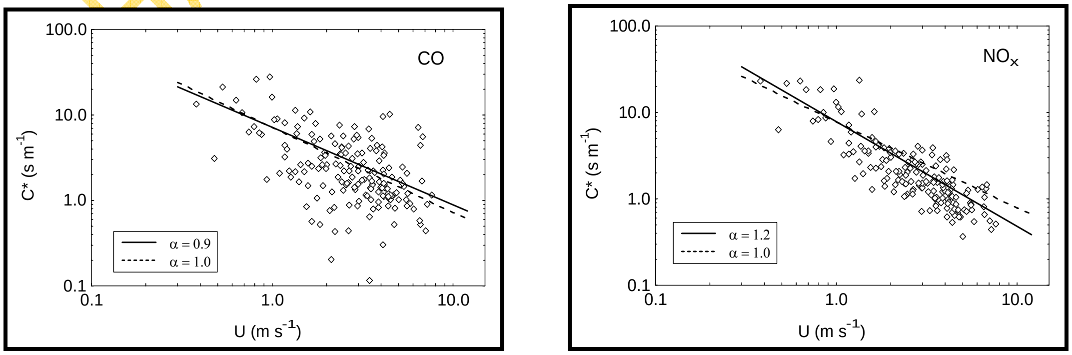

Fig. 2; Variation of normalised concentrations, $C^*=(C_i-C_b)W/E$, with ambient wind speed (U) when θ= 270° obtained for CO and NO_x concentrations.

Plotting the variation of C* with ambient wind speed (U) we obtain the best fitting curves to the expressions (see Figure 2):

$$C^* = (a^{1/2}\,U)^{-1} \qquad (3) \qquad \text{and} \qquad C^* = (A^{1/2}\,U^{\alpha})^{-1} \qquad (4)$$

Considering all cases 180º<θ<360º, we obtain the values of *a* from equation (3) and the values of *A* and α from equation (4). Figure 3 shows the variation of *a* with θ. The parameter *a* varies from 0.009 (θ=337.5º) to 0.019 (θ=247.5º, θ=270º). Figures 4 and 5 show the variation of *A* and α with θ, respectively. The lower value of *A* [≈0.008$(\text{m s}^{-1})^{2(1-\alpha)}$] has been obtained with α≈ 0.6 (θ=202.5º) and the highest *A*≈ 0.019$(\text{m s}^{-1})^{2(1-\alpha)}$ is associated to α≈ 0.9 (θ=247.5º). The regression coefficients are slightly greater if $C^* = (A^{1/2}\ U^{\alpha})^{-1}$ is considered.

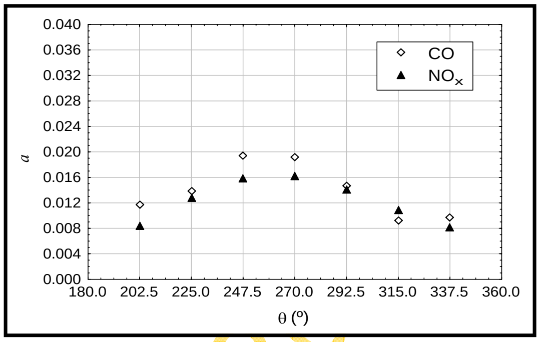

Fig. 3; Variation of a with θ.

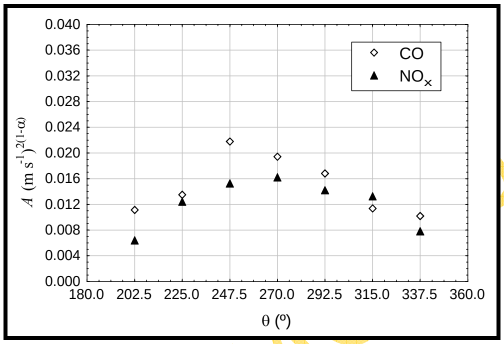

Fig. 4; Variation of A with θ

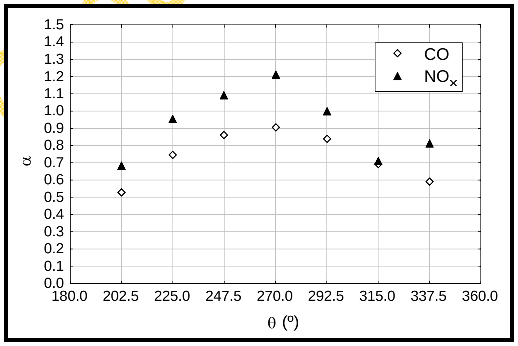

Fig. 5; Variation of α with θ.

b) Analysis if "leeward cases" data (0º≤ θ ≤180º)

In these cases it can be assumed that normalised concentrations verifies the relationship $C^* \propto (u_s)^{-1}$. Several authors (*Ketzel M. et al.*, 2002, *Kastner-Klein P. et al.*, 2001, 2003, *Mazzeo, N. and L. Venegas,* 2005) have studied the variation of street level concentration with U for wind directions close to leeward condition (in this study, θ≈90º) and they have found that for wind speeds lower than 5 m s^{-1}, the fitting curve considerable deviates from $C^* \propto U^{-1}$ (representative of the "without traffic turbulence" condition). The wind speed for the transition between "with" and

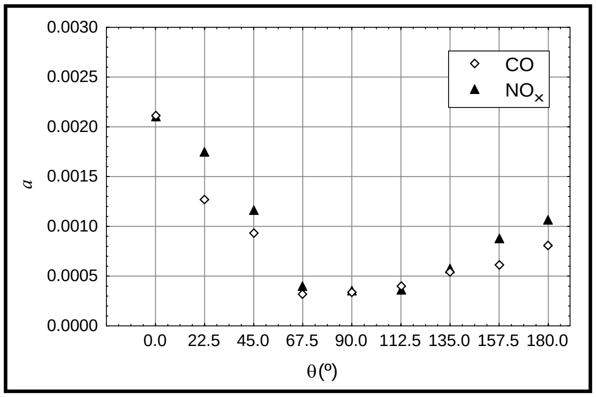

Fig. 6; Variation of a with θ.(leeward) "without" traffic turbulence regimes depends on the traffic conditions. Considering the "leeward cases" (0º≤ θ ≤180º) and U≥5m s^{-1}, and assuming $C^*=(a^{1/2}U)^{-1}$, we obtain the variation of *a* with θ (results on Figure 6). The values of *a* varies between 0.00035 (θ=90º) and 0.0021 (θ=0º).

Knowing *a*, the values of *b* can be obtained from equation (2). The variation of *b* with traffic density (N/V) (N is traffic volume) for different θ is shown in Figure 7.

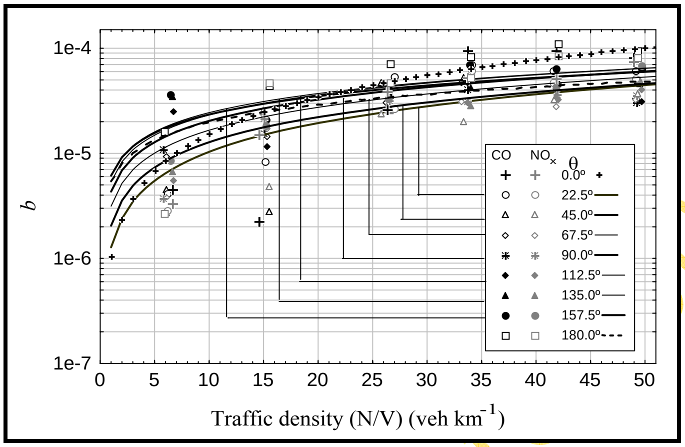

Fig. 7; Variation of b with traffic density and θ

Data of both pollutants have been fitted to

$$b(N/V;\theta)=m(N/V)^n \qquad (5)$$

$$m= -1.033E\text{-}06 -4.599E\text{-}09\ \theta +7.514E\text{-}10\ \theta^2 -3.27864E\text{-}12\ \theta^3 \quad \text{and} \quad n=2.7642(\theta+17.11)^{-0.3021}$$

These expressions are valid for 5veh km^{-1}≤(N/V)≤ 50veh km^{-1}.

Finally, we study the variation of the critical wind speed (U_c) (that verifies $aU_c^2=bV^2$) with traffic density and wind direction. Results are included in Figure 8, along with the curves obtained fitting to

$$U_c(N/V;\theta)=p\ \exp[q(N/V)] \qquad (6)$$

with

$p= (0.56288+0.014633\ \theta +1.495E\text{-}04\ \theta^2 - 1.078E\text{-}06\ \theta^3)$

$q= (0.0272043-0.0003261\ \theta + 1.3407E\text{-}06\ \theta^2)$.

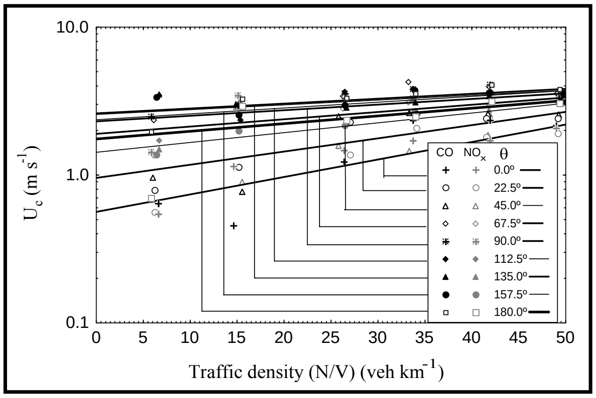

Fig. 8; Variation of U_c with traffic density and θ

CONCLUSIONS

We analysed hourly traffic pollution data (CO and NO_x concentrations, wind data and traffic flow) registered in a street canyon of Göttinger Strasse (Hannover, Germany). All wind directions have been considered in this study. For "windward cases", the variation with wind direction (θ) of parameters *a*, *A* and α were obtained from $C^*=(C_i-C_b)W/E=(a^{1/2}U)^{-1}$ and

$C^{*}=(A^{1/2}U)^{-\alpha}$. These variations were: $0.009 \leq a \leq 0.019$, $0.008(\mathrm{m\ s^{-1}})^{2(1-\alpha)} \leq A \leq 0.019(\mathrm{m\ s^{-1}})^{2(1-\alpha)}$ and $0.6 \leq \alpha \leq 1.1$. Considering the "leeward cases" (including wind directions parallel to the street) with $U \geq 5$ m s^{-1}, the values of a varied from 0.00035 (θ=90º, wind perpendicular to the street axis) to 0.0021 (θ=0º, wind parallel to the street axis). For "leeward cases", using the expression $C^{*}= (aU^2+bV^2)^{-1/2}$ and knowing a, estimated b varied between ~3.0E-06 and ~1.0E-04, depending on wind direction (θ) and traffic density (N/V). We obtained an empirical expression for b as a function of θ and (N/V). We obtained the values of the critical wind speed (U_c) (that verifies $aU_c^2=bV^2$) for all "leeward" cases (including wind parallel to the street) and an empirical form of U_c= f(N/V;θ).

ACKNOWLEDGEMENTS

This work has been supported by Projects UBACYT-X060, FONCYT PICT2000 Nº13-09544 and CONICET-PIP 6169. The traffic pollution data used in this paper are available on www.dmu.dk/atmosphericenvironment/Trapos/datadoc.htm, within the framework of the European Research Network on Optimisation of Modelling for Traffic Pollution in Streets (TRAPOS).

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