1.08 USE OF WIND TUNNEL EXPERIMENTS OF TRACER DISPERSION FROM A LANDFILL FOR MATHEMATICAL MODELS VALIDATION

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INTRODUCTION

Dispersion modelling of a tracer emitted from a landfill is a particularly difficult task, because of the localised turbulent flow field around the landfill relief. In this specific case, small-scale experimental results are very useful for developing, improving or testing numerical codes, which up to now rely strongly on empirical parameters and/or on field data sets that are affected by large uncertainties. In this work, experimental wind tunnel data (some of the experiments have been described in *Carpentieri, M. et al.*, 2004) have been used as a reference, in order to evaluate mathematical models performances. The comparison of the results has been performed basing on statistical methods.

EXPERIMENTAL SET-UP

The experiments were undertaken in the environmental boundary layer wind tunnel of CRIACIV in Prato, Italy. The small-scale model (scaling factor 1:200) is truncated-pyramid-shaped with a square base. An accurate evaluation of the characteristic flow inside the tunnel, with and without the presence of the landfill, was performed in previous studies (Zipoli, L., 2002; Carpentieri, M. et al., 2004). Emission velocity is very small and can be neglected for our purposes. Thus, as described in (Carpentieri, M. et al., 2004), there are no limitation for the reduced scale wind velocity, and the equation:

$$\left(\frac{CU_{ref}H_{ref}^2}{Q}\right)_{full-scale} = \left(\frac{CU_{ref}H_{ref}^2}{Q}\right)_{model} \quad (1)$$

is verified for all wind velocities (see also Obasaju, E.D. and A.G. Robins, 1998). In eq.(1) the terms represent the normalised concentration, using a reference wind speed (in this case U_{ref} is the velocity at the boundary layer edge) and a reference length (see table 1 for H_{ref}). A description of the instrumentation and the experimental strategy can be found in (Carpentieri, M. et al., 2004).

In addition, other vertical, transversal and longitudinal concentration profiles have been carried out in new experiments with different wind speeds (2, 5 and 10 m/s at $z/H_{ref} = 0.07$).

Table 1. Full-scale and reduced scale model parameters (Carpentieri, M. et al., 2004).

PARAMETER	FULL SCALE	REDUCED SCALE
Source height	15 m	0.075 m
Roughness length (z_0)	0.05 m	$2.5\cdot10^{-4}$ m
Tracer flow rate (Q)	0.032 m^3/s	$8.0\cdot10^{-6}$ m^3/s
Vertical emission velocity (W_{em})	$3.9\cdot10^{-6}$ m/s	$3.9\cdot10^{-5}$ m/s
Wind profile exponent α_p	0.155	0.155
Wind velocity at height $z/H_{ref} = 0.07$ (U_{10})	---	2 m/s
Wind velocity at source height (U_{em})	---	2.13 m/s
Roughness Reynolds number (u^*z_0/υ)	---	2.3
Density ratio (ρ_{gas}/ρ_a)	1	1
Boundary layer depth (H_{ref})	140 m	0.7 m

MATHEMATICAL MODELS

This case study has two main difficulties for the mathematical dispersion models: the presence of an area source and the downwash effect induced by the landfill relief. Most of the numerical codes have been developed for elevated point sources. Up to now there isn't a model specifically designed to simulate area sources near the ground. However many dispersion codes are able to simulate area sources with good approximation. The downwash effect observed in the wind tunnel experiments (*Carpentieri, M. et al.*, 2004) is a phenomenon analogous to the well-known "stack-tip downwash" effect and "building downwash" effect. Although many methods for the implementation of these effects in the models exist, no studies are available for the considered case, where there is an emission from a large area source on the top of a truncated-pyramid-shaped relief, not far from the ground. The importance of understanding this phenomenon is due to the increase of the ground level concentrations near the source.

In the present work the use of SAFE-AIR was performed in order to evaluate the relative capability in applying the model to the specific studied case. The SAFE AIR modelling system consist mainly of a meteorological pre-processor WINDS (*Ratto, C.F.,* 1996), which builds a three-dimensional wind field, and a dispersion code P6 (e.g. *Canepa, E. et al.*, 2000; *Canepa, E. and C.F. Ratto*, 2003), which perform the dispersion calculations. There is also a micro-meteorological pre-processor (ABLE), for the calculation of boundary layer parameters, but it has not been used in this work. Three different simulations have been performed. The source has been divided in 36 point sources covering the whole area. This value has been chosen after a sensibility analysis, agreeing with the results of other studies (*Cavallaro, M. et al.*, 2003). The first and the second simulation (indicated respectively with SA1 and SA2) have been performed with the Briggs Open Country σ-functions, while the third simulation (indicated with SA3) has been performed using the Pasquill-Gifford-Turner σ-functions. No downwash effects were accounted for in the first simulation (SA1). In the second (SA2) and in the third simulation (SA3) the "building downwash" option was used, approximating the landfill relief as a cubic building. Other σ-functions (Briggs Urban, Brookhaven National Laboratory) have not been considered, because they were developed for different conditions (i.e. elevated sources or high roughness length).

In order to compare experimental data and SAFE AIR data with another model, specifically built for near-ground releases, the model for vertical concentration distribution, originally proposed by *Van Ulden, A.P.* (1978), has been chosen. According to his model and some following papers (*Gryning, S.E. et al.*, 1983; *Sarkar, U. and S.E. Hobbs*, 2003) the concentration can be calculated using:

$$C(x,y,z) = \left\{ \frac{Q_p}{\bar{u}} \cdot \frac{A}{\bar{z}(x)} \exp\left[-\left(\frac{B \cdot z}{\bar{z}(x)} \right)^s \right] \right\} \cdot \left\{ \frac{1}{\sqrt{2\pi} \cdot \sigma_y} \exp\left[-\frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \right\} \quad (2)$$

where Q_p is the source strength of the unit surface point source (m^3/s), $\bar{u}$ is the effective speed (m/s) of plume advection at the mean height of the plume, $\bar{z}$ (m), and at y=0, $A=s\cdot\Gamma(2/s)/\Gamma^2(1/s)$, $B=\Gamma(2/s)/\Gamma(1/s)$ are functions of the shape parameters (s) and s is determined (*Gryning, S.E. et al.*, 1987) by the growth of the vertical spread with distance, Γ is the gamma function, σ_y is the standard deviation of the lateral spread (m). The expressions for $\bar{u}$, $\bar{z}$ and s are taken from *Van Ulden, A.P.* (1978) and *Gryning, S.E. et al.* (1983) and, for the present study, these are computed with standard numerical schemes. σ_y is calculated using Pasquill-Gifford-Turner σ-function. Two different simulations have been performed. As in the SAFE AIR models, the area source was approximated using 36 point sources. The first simulation (indicated with VU1) has been performed using the actual source height to calculate $\overline{z}$. For the second simulation (indicated with VU2), on the contrary, an effective plume height, h=0, was used, in order to account for the downwash effect. A sensibility analysis with respect to the effective plume height has also been performed.

RESULTS AND COMPARISON

Comparison between wind tunnel data and calculated data has been performed on the basis of concentration profiles and statistical indices. Some of the profiles (and comparisons with model results) are shown in figure 2. It can be observed that wind tunnel concentrations at ground level are sensibly higher than mathematical codes concentrations when no downwash effect algorithm is applied (i.e. SA1 and VU1). Another important difference in the behaviour of the plume can be observed in the vertical profiles. Vertical profiles of SA1 and VU1 are not comparable at all with experimental data, particularly at lower distances from the source. A better description for the vertical profile is given by SA2, SA3 and VU2.

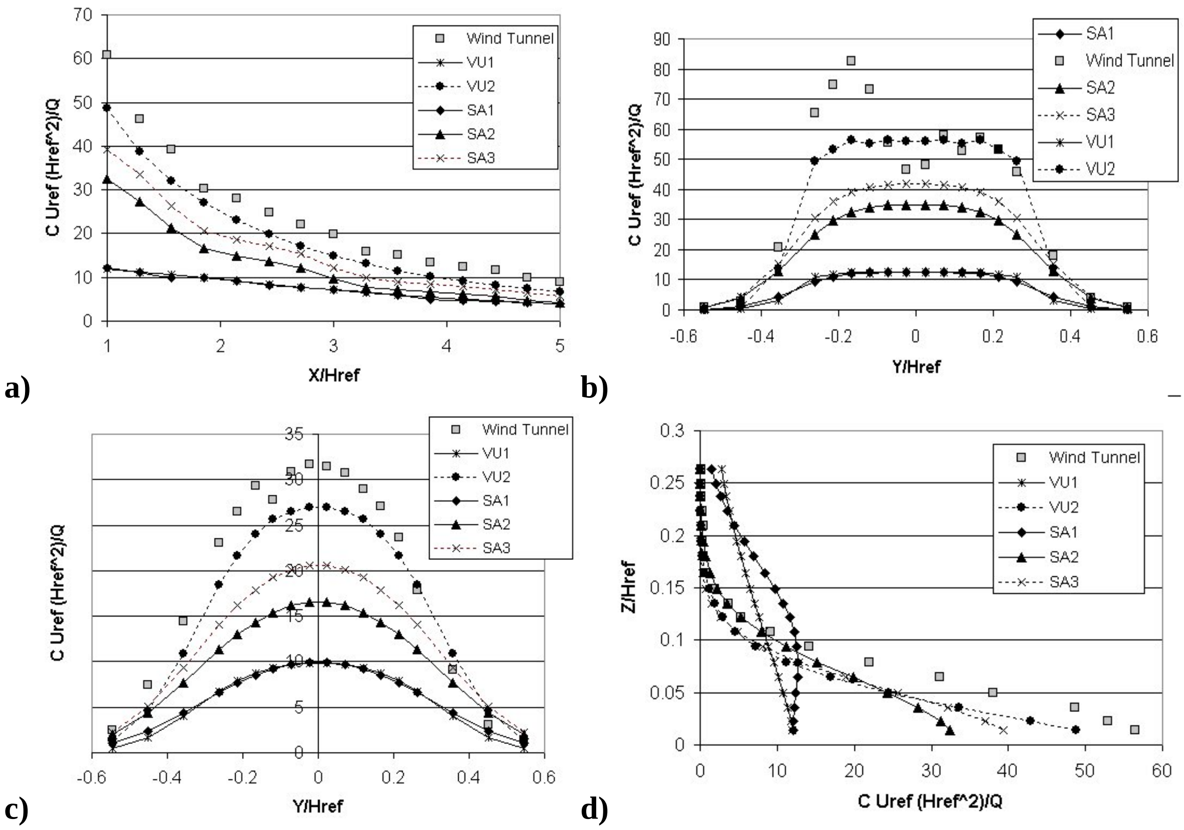

Figure 2. (a) Ground-level (z/H_{ref}=0.014) concentrations (centre-line); (b) Transversal normalised concentration profiles at z/H_{ref} = 0.014 and x/H_{ref} = 0.86; (c) Transversal normalised concentration profiles at z/H_{ref} = 0.107 and x/H_{ref} = 1.86; (d) Vertical normalised concentration profiles at x/H_{ref} = 1.

In order to perform models validation and models inter-comparison some of the statistical indices described in *Canepa, E. and P.J.H. Builtjes* (2001) have been used (see also *Corti, A. et al.*, 2001). Statistical indices are applied to all measured and calculated data, as shown in table 2, using wind tunnel results as reference. Table 3 and table 4 describe, respectively, the application of these indices to the ground-level concentrations and to the vertical profiles only.

Table 2. Statistical indices calculated using all available data.

MODEL	FB	FS	COR	FA2	NMSE	WNNR	NNR
Wind Tunnel (ref.)	0	0	1	1	0	0	0
Van Ulden 1	0.85	1.3	0.82	0.39	2.53	2.7	0.75
Van Ulden 2	0.23	0.14	0.96	0.84	0.15	0.16	0.21
SAFE AIR 1	0.77	1.25	0.68	0.43	2.3	2.58	1.07
SAFE AIR 2	0.46	0.63	0.96	0.83	0.64	0.65	0.36
SAFE AIR 3	0.35	0.43	0.96	0.84	0.36	0.37	0.28

Table 3. Statistical indices calculated using ground-level concentration data.

MODEL	FB	FS	COR	FA2	NMSE	WNNR	NNR
Wind Tunnel (ref.)	0	0	1	1	0	0	0
Van Ulden 1	0.94	1.27	0.82	0.32	2.7	2.72	0.84
Van Ulden 2	0.18	0.11	0.97	0.91	0.1	0.1	0.14
SAFE AIR 1	0.88	1.27	0.7	0.38	2.54	2.7	1.39
SAFE AIR 2	0.49	0.67	0.95	0.82	0.66	0.67	0.44
SAFE AIR 3	0.34	0.46	0.96	0.91	0.34	0.35	0.22

Table 4. Statistical indices calculated using vertical concentration profiles.

MODEL	FB	FS	COR	FA2	NMSE	WNNR	NNR
Wind Tunnel (ref.)	0	0	1	1	0	0	0
Van Ulden 1	0.63	1.37	0.89	0.54	2.1	2.53	0.6
Van Ulden 2	0.37	0.28	0.96	0.71	0.36	0.36	0.37
SAFE AIR 1	0.52	1.19	0.71	0.55	1.76	2.18	0.55
SAFE AIR 2	0.39	0.55	0.98	0.86	0.53	0.54	0.22
SAFE AIR 3	0.38	0.39	0.98	0.71	0.39	0.4	0.42

The FB values result always positive, showing the models tendency to underestimate on average measured data. Also dispersion around mean value is always higher for experimental results than the simulated ones, as shown by FS index positive values. All the tables show that the best performance with respect to the reference data is given by VU2 model, i.e. Van Ulden model applied with an effective source height equal to 0. Also SA2 and SA3 models show a good agreement with experimental data, in particular for vertical profiles. SA1 and VU1 models have always the worst performances with respect to the reference model. Comparing the three tables can be observed that the main difficulties for the VU2 model are in the calculation of vertical profiles, while the best agreement is for the ground-level concentrations, as shown by figure 2 too.

CONCLUSIONS

Dispersion modelling is an important part of the process of assessing and managing air quality in cities and in proximity of high pollutant processes. Simulating tracer dispersion from a landfill is a complex task, limited by many simplifying assumptions and modelling uncertainties. In particular the behaviour of the plume immediately downwind from the landfill relief cannot be correctly modelled by standard mathematical models for local and regional scale applications. The results given in this paper can be useful as a first step towards the investigation of the phenomenon, although more studies are necessary before the implementation of dedicated algorithms. The comparison applied in this paper has shown that the downwash effect has a main role in the definition of ground-level concentrations near the source. In particular, models have many difficulties in the simulation of vertical concentration profiles. This is probably due to the fact that most of the models were developed for high point sources, with different dispersion characteristics. Further, the presence of the downwash effect gives more complexity to the system, resulting in an increase of the ground level concentrations near the source. For these reasons the best performances have been given by models applied with an adjusted source height, accounting for the downwash effect in some manner. In particular a statistical comparison method has shown that the best performances with respect to the experimental data are given by Van Ulden model with a source height arbitrarily set to 0.

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