

# Dispersion modeling of pollutants released from road tunnel portals

A contribution to subproject SATURN

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## Summary

During the year 2001 the research work of the group was mainly dedicated to the investigation of the particular dispersion conditions in the vicinity of road tunnel portals. A national funded research project enabled comprehensive air quality measurements, SF<sub>6</sub>-tracer tests in the vicinity of a road tunnel portal in Austria, and theoretical work to develop a suitable dispersion model for road tunnel portals. Seven tracer experiments on two days formed the basis for the model development. During all experiments wind speeds were quite low ranging from 0.6 to 1.6 m s<sup>-1</sup>. The main results that could be drawn from the field measurements were a strong dependency of the jet stream from the tunnel portal on the ambient wind field. Due to the observed great changes in wind direction during each of the experiments (meandering of the flow), the position of the jet stream varied also enormously, i.e. receptor points in the vicinity of the tunnel portal were only exposed to the polluted air of the jet stream for a certain time during each of the experiments. This specific effect was found to be more important than the diffusion due to shear stresses along the surface between the jet stream and the ambient wind field. A rather simple dispersion model could be developed, which is based on a Lagrangian formulation of the dispersion process. The model is able to treat the momentum of the jet stream, buoyancy effects due to temperature differences between the jet stream and the ambient air, and the influence of changing wind directions of the ambient flow on the position of the jet stream. It is the first time, that the latter process is considered in a dispersion model for road tunnel portals. Results with the new model were compared with observations of the tracer tests and with results from a microscale Eulerian model using a standard k-ε model. While the new model gave reasonable concentrations compared to the observations, the k-ε model overestimated concentrations by a factor of 10 in the centre of the jet stream. This result was not surprising due to the circumstantial, that the Eulerian model can not treat the changing position of the jet stream.

## Aim of the research

Increasing road traffic, especially in and around cities, demands for practical solutions to avoid major congestions and to keep away the noise and air pollution from residential areas. Roadway tunnels become more and more the solution for all these problems, but they also may cause high pollution concentrations in the vicinity of the portals, when a tunnel is ventilated longitudinal. This is mostly the case in one-way roadway tunnels, because the thrust of cars inside the tunnel then supports the ventilation and thus, saves running costs.

There is a strong need for air quality models, which can treat the special dispersion conditions from tunnel portals and in addition, which are suitable for environmental assessment studies. Hence, they should require a minimum of computation time on conventional personal computers. From that point of view, Eulerian microscale models (Large eddy simulation, Reynolds averaged Navier-Stokes equations) are not a proper choice for that purpose, since they are not easy to handle, and still consume much CPU-time, if run on a PC. Therefore,

such models can mainly be applied for single case studies and their applicability to calculate statistical concentration values (percentiles, annual mean) is rather limited. In addition, the computational domain has to be kept small, and it is not always possible to calculate an adjacent street network or other sources (point, area) simultaneously.

### **Activities during the year**

Activities during 2001 were the set up and implementation of seven SF<sub>6</sub>-tracer tests in the vicinity of a road tunnel portal situated in an inneralpine basin in Austria. Approximately 25 receptors were mounted 1 m above ground level around the portal up to distances of 200 m. Concentrations were determined by the use of a FT-IR device allowing for an accuracy of +/- 5%. Long-range measurements of standard pollutants (CO, NO<sub>x</sub>, SO<sub>2</sub>, PM10) were performed over several months as well as path-measurements of pollutants like NO<sub>x</sub> and Benzene with a DOAS device. Meteorology was observed by means of three sonic anemometers, one installed 10 m a.g.l. to capture the ambient wind flow, and the others installed at street level to allow for turbulence measurements of the jet stream. Two tracer tests were performed at the southern portal of the Katschberg tunnel in Austria, which is situated in highly complex terrain. In the course of the year a simple dispersion model could be developed and tested against all tracer tests.

### **Principal results**

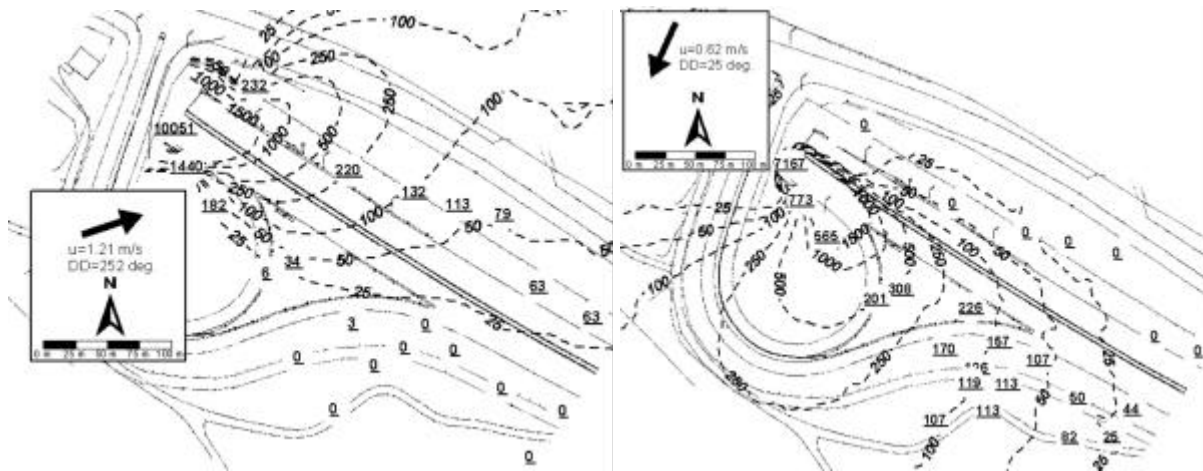
One important process found in the investigations of the tracer experiments conducted, was the influence of the changing ambient wind field direction (meandering) on the position of the jet stream of the tunnel portal. The position changes are of the order of decameters, while the characteristic length scales of eddies evolving at the surface between the jet stream and the ambient wind field are of the order of some meters. To the best of the authors knowledge it is the first time that this effect is being described and included in a dispersion model. The model is based on a Lagrangian formulation, i.e. single particles are tracked, whose velocities are determined by the prevailing ambient wind field and the features of the jet stream (exit velocity, temperature difference between the jet stream and the ambient wind field). Buoyancy effects are accounted for in the model in following the suggestions of Van Doop (1992) for point source releases. The computation of the shape of the jet stream is largely based on Bernoulli's equation. For instance, it is assumed that the ambient wind causes a pressure upon the jet stream, which changes the direction of the jet stream and slows it down or accelerates it depending on the wind speed differences between ambient wind and jet stream. After a certain time the jet stream owns the same wind speed and direction as does the ambient wind field. The subsequent calculations are then implemented with the dispersion model GRAL (Oettl et al. 2001a, Oettl et al. 2001b).

Fig. 1 shows two examples of calculated concentrations with the new model for two different SF<sub>6</sub>-tracer tests.

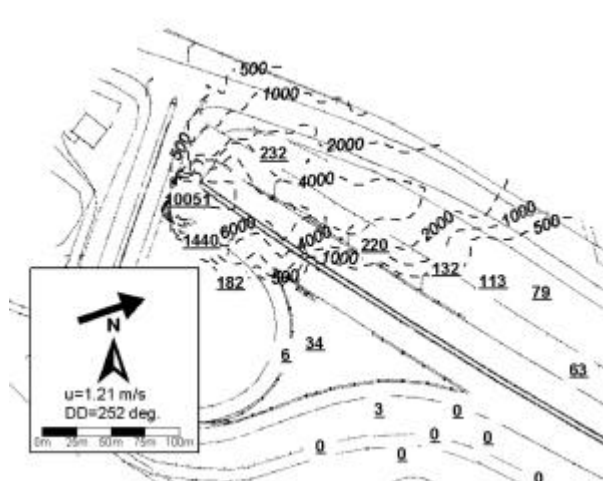
It can be seen, that there is a fairly good agreement between observed concentrations and modelled ones. Observations were also compared to simulations with a microscale Eulerian model, which does not account for the particular dispersion process as described above. The result for experiment 1 can be seen in Fig. 2

The Eulerian model, which uses a k-ε turbulence model, overestimates concentrations at the centre line of the jet stream by about a factor of ten. The reason is most probably the

neglecting of the changing wind directions of the ambient wind field and the resulting changes in the position of the jet stream.



**Figure 1.** Modelled (Italic numbers, dashed lines) and observed (underlined) concentration distributions for tests 1 (left) and 4 (right) of the tracer experiments near a motorway road tunnel in Austria.



**Figure 2.** Modelled (Italic numbers, dashed lines) and observed (underlined) concentration distribution for test 1 of the tracer experiments near a motorway road tunnel in Austria.

### Main conclusions

The model presented here is applicable in a Lagrangian framework, which has the advantage, that different shapes of sources (point-, area-sources, complex street network configurations) can be modelled simultaneously, and in addition without discretization errors. The model can easily be run on a conventional PC and hence, can be applied for regulatory purposes. Although the model contains many simplifications, it was successfully tested, but not validated, against a tracer-gas experiment taken near a motorway tunnel portal in Austria. Nevertheless, the good performance of the model for the tracer tests used in this study, raises the hope, that it can also be successfully applied for other road tunnel portals.

It should be emphasized, that the dispersion of a jet stream in combination with ambient low wind speeds, is perhaps one of the most challenging tasks in air quality studies, and that there is currently no model available, which is able to treat both effects properly. E.g. Eulerian

microscale models solving the set of conservation equations can not treat the effect of meandering, and the influence of the wind direction fluctuations on the position of the jet stream centre-line.

The model presented may not be applied, when specific features near the road generate significant wakes, such as high noise abatement walls, buildings, etc., but it can also be combined with a proper wind field model to account for topographical effects on the ambient wind field.

### **Aims for the coming year**

It is planned to perform additional tracer tests at other tunnel sites to generate data sets for the validation of the new model. Unfortunately, existing data sets, such as from the Japanese Highway Association are not available currently, or not suitable for validation purposes. A national research project regarding dispersion during low wind speeds is being proposed to further investigate the particular problems in such situations (meandering, non-stationary flows, etc.). Further validation work is also planned with the Lagrangian model GRAL (Öttl et al. 2002a, Öttl et al. 2002b).

### **Acknowledgements**

The research work was funded by the Austrian research fond project No. 14075-TEC.

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