FLOW AND DISPERSION IN THE ATMOSPHERIC BOUNDARY LAYER INVESTIGATION BY PHYSICAL MODELLING

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Summary The method of physical modelling has been adopted, a new environmental wind tunnel was designed and some methods of measurement have been developed at the Institute of Thermomechanics AS CR. The following examples of results are demonstrated: air pollution due to traffic inside a street-canyon, plum of smoke spreading over complex terrain, the surface mean concentrations of lead from point source assessment.

PHYSICAL MODELLING

Air pollution is enacted on various geographical and temporal scales, running from strictly "here and now" problems to global phenomena, which over the next centuries can change the conditions for man and nature entire globe. Study of the dispersion of pollutants in the atmosphere forms a basis for implementation of effective methods to prevent environmental damage. The main source of information for solving of environmental and wind engineering problems is mathematical modelling and a laboratory simulation of the Atmospheric Boundary Layer (ABL) in specialised wind tunnel so called physical modelling. The principle of physical modelling consists in analogy between a boundary layer formed over the floor of a wind-tunnel working section and the Atmospheric Boundary Layer. Following general requirements for similarity of the boundary layer with the Atmospheric Boundary Layer (ABL) have to be fulfilled in order to transfer results from small-scale wind tunnel experiment (model) to full scale (prototype):

- undistorted scaling of geometry,
- equal Reynolds number Re,
- equal Prandtl number Pr,
- equal Richardson number Ri,
- equal Eckert number Ec,
- surface-boundary-conditions similarity,
- similarity of the approach-flow characteristics

EXPERIMENTAL TECHNIQUE

However, the requirements cannot be satisfied simultaneously in existing facilities and a partial or approximate simulation for particular application has been worked out. These methods have been adopted and a new environmental wind tunnel was designed at the Institute of Thermomechanics Academy of Science Czech Republic. The tunnel is designed as an open-circuit facility that is operated as a fan driven one. It has the cross section 1.5 m x 1. 5 m and the length to the working section 25.5 m. The long test section achieve sufficiently thick boundary layer on the wall of the working section (cca 0.3 m) with the necessary dependent variables profiles. The tunnel inlet is formed by elliptic elements inside of a suction tower with 64 m^2 screens and of size 6 m x 6 m x 12 m preventing external disturbances. It follows a corner with 17 vanes with the gap between thin sheet metal vanes h = 0.1248 m and the chord c = 0.312 m. An aluminium honeycomb made for aircraft sandwich and 6 screens with screen open area ratio ß = 0.57 and 0.79 placed behind the corner guarantee that the wind tunnel meet all demands of a first class aerodynamics facility. The working section of the length 2-m with glass sidewalls follows a section of lights and the two corners. A 30 kW centrifugal blower drives the tunnel at the exit. The velocity at the working section is within interval (0,1, 13) ms^{-1} and depends upon number of revolutions per second.

To solve and investigate all necessary flow and dispersion characteristics in aerodynamic wind tunnel, it was necessary to develop and to adapt some new methods of measurement. First of all, there was demand for flow visualisation and for application of such a method for rough introduction and approximation. We were using during that time common system consisting from fog generator, laser light sheet, digital camera/video camera and Pentium based computer for processing. An example of the plume spread visualisation is demonstrated on fig. 1 The turbulence characteristics of the flow field were measured by a 2D fibre-optic Laser Doppler Anemometer (DANTEC) with 500 mm focal distance of the Meteorological Institute Hamburg. The slow Flame-Ionisation-Detector (Rosemount Analytical NGA 2000-TFID) and $C0_2$ laser photoacoustic spectrometry are used for mean concentrations measurements.

RESULTS

A few examples of acquired applications is demonstrated:

- Flow and dispersion on the street scale was investigated in the framework of COST 715 project. The street scale is important for urban air pollution problems because of most urban emissions occur within the canopy layer, where buildings heavily disturb the atmospheric flow. Therefore two main types of tasks have been investigated: simplified, generalized situations of the street canyon and direct solution of geometric complex situations. The methods of the urban type inflow simulation, small-scale flow simulation and dispersion simulation including a modelling with a line source model were developed in both cases in the scale 1:200. An appropriate configuration of roughness elements and spires made the approaching boundary layer flow, which corresponds with the neutrally stratified urban atmospheric boundary layer. The models of a street canyon with one line permeation pollution source developed in this work as an example of the first type of the street scale problem and model of "Podbielski Strasse in Hannover" with two parallel lines sources, an example of the second type, were manufactured. The similarity criteria have been proved at first. It means that our experimental results can be transferred to full scale. The concentration field of passive contaminant was measured inside the model street canyon and inside of "Podbielski Strasse" and dimensionless field of concentrations across the streets were assessed. Comparison demonstrates differences it the concentration fields, e. g. the leeward side of the "Podbielski Strasse" is heavily polluted, etc. The assessed concentration field demonstrates that the living conditions inside the street are out of the proposed EC directives.
- Processes in the ABL over Orlice River basin were investigated using a geometric scale of 1:1000 and Reynolds number independence method was used. Influence of effective high of the stack has been investigated by visualization technique and surface mean concentration from two point sources inside the urban area has been assessed.
- The surface mean concentrations of lead from KOVOHUTE work, the Czech Republic in complex terrain was assessed. The aim of the search was to assess the KOVOHUTE work contribution to air pollution in the region and its development. The heavy polluted area with diameter of 4.5 km was traced and a model of a landscape on scale 1:6000 including the stack model was manufactured and mounted on a turntable into special aerodynamic wind tunnel of the Institute of Thermomechanics. Approximate similarity of flow in which a laminar flow structure is dominated by the surface geometry had been applied for simulation. Qualitative analysis of the plume spread by visualization method demonstrated that the plume direction is not influenced by the morphology. Then the years mean concentrations have been assessed for different emission situations and the surface concentration fields are compared to demonstrate air pollution progress.

CONCLUSION

Processes in the Atmospheric Boundary Layer are complicated by the combined influences of the Earth's rotation, buoyancy forces, surface drag forces, the geometry of topographic features etc. It is extremely difficult to solve this synergetic problem analytically and experiments in situ are expensive and give only particular results. The method of physical modelling becomes a powerful tool in the ABL search. Its application has been demonstrated for some cases investigated in the Institute of Thermomechanics AS CR.

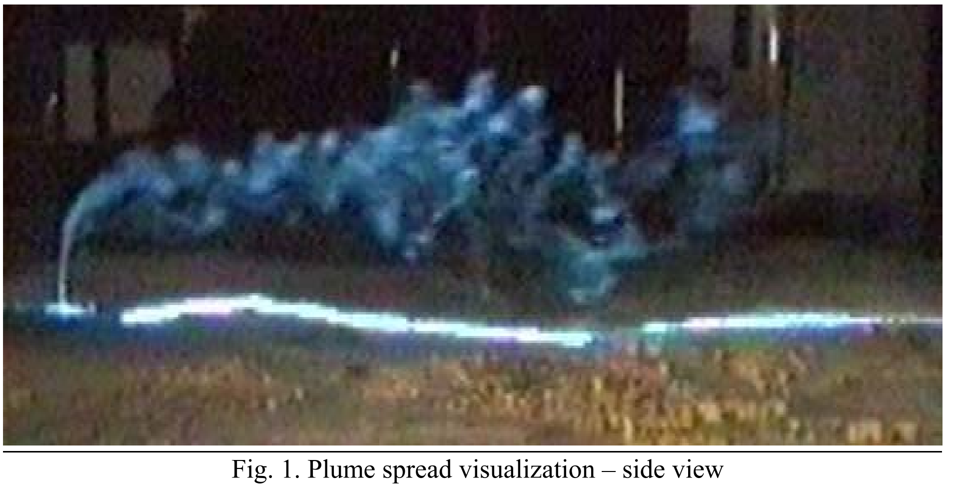

Fig. 1. Plume spread visualization – side view