# DISPERSION OVER OPEN-CUT COAL MINE - WIND-TUNNEL MODELLING STRATEGY

**Nosek Š., Jaňour Z., Jurčáková K., Kellnerová R., Kukačka L.**
**Institute of Thermomechanics AS CR, v.v.i., Prague**

## Introduction

Atmospheric boundary layer (ABL) is a domain of interest of wind flow simulation and dispersion processes over complex terrain. The layers of ABL are complicated by the combined influences of the Earth's rotation, buoyancy forces, surface drag forces, and geometry and topography features. The thickness of ABL is quite variable in time and space, ranging from $10^2$ to $10^3$ meters. This paper does not present the comprehensive review of wind flow and dispersion wind-tunnel modeling over open-cut coal mines. Rather, important works are presented to withdraw the main features of wind-tunnel possibilities to model flow over extensive terrain where the characteristic (horizontal) length is bigger than 5 km; in particular over the open-cut coal mine in Tušimice.

## Wind-tunnel modeling constrains

Standards for physical modeling of atmospheric diffusion in wind-tunnels are described in Snyder (1981). In order to model non-buoyant plume dispersion in neutrally stratified flow the following similarities between model and prototype need to be satisfied: geometric similarity, Reynolds number equality, Prandtl number equality (when air is used in the model, the Prandtl numbers are automatically equal), and boundary-condition similarity (including approach flow and surface roughness). Fulfill the geometric similarity is not difficult task. The problems emerge if we want to fulfill the Reynolds number similarity. If we consider the typical range of model scale using in wind-tunnels (1:200 to 1:1000) it's apparent that Reynolds number can't be fulfilled unless we can perform extremely high wind speeds (several hundred m.s$^{-1}$). Thus, if strict adherence to the Reynolds number criterion were required, no atmospheric flows could be modeled.

Arguments which attempt to justify the use of smaller Reynolds number in model may be divided into three general categories as reported by Snyder (1981): the laminar flow analogy, the Reynolds number independence, and the dissipating scaling. Simulation of neutral stratified flow above complex terrain, where the characteristic (horizontal) length is bigger than 5 km, demands the scale of order 1:$10^4$ m with respect to wind-tunnel dimensions. In such case of model scale the laminar flow analogy should be used in order to satisfy the Reynolds number criteria.

## The laminar flow analogy

This concept was introduced by Abe (1941) and widely used by Cermak (1971, 1984), and Janour (2002). If the instantaneous velocity, temperature, and pressure in N-S equation are written as the sum of mean and fluctuating parts ($U_i = \bar{U}_i + u_i$), and the equation is then averaged, the following equation is obtained:

$$\frac{\partial \overline{U}_i}{\partial t} + \overline{U}_j \frac{\partial \overline{U}_i}{\partial x_j} + 2\varepsilon_{ijk}\Omega_j \overline{U}_k = -\frac{1}{\varrho_0}\frac{\partial \overline{\delta P}_i}{\partial x_i} + \frac{g}{T_0}\delta\overline{T\delta_{3i}} + \nu \frac{\partial^2 \overline{U}_i}{\partial x_j \partial x_j} - \frac{\overline{\partial u_i u_j}}{\partial x_j}, \qquad 1.$$

where the $x_3$ axis is taken vertically upward, $U_i$ is instantaneous velocity in i-direction, $u_i$ is fluctuating velocity, $\delta P$ and $\delta T$ are deviations of pressure and temperature from those of a neutral atmosphere, $\rho_0$ and $T_0$ are density and temperature of a neutral atmosphere (functions of height), $\nu$ is kinematic viscosity, $\varepsilon_{ijk}$ is the alternating tensor, $\delta_{ij}$ is Kroneker's delta. An eddy viscosity $K$ can be defined to relate the Reynolds stress to the mean velocity: $-\left(\overline{u_i u_j}\right) = K\left(\frac{\partial U_i}{\partial x_j}\right)$. The nondimensional equation is then

$$\frac{\partial \overline{U}_i}{\partial t} + \overline{U}_j \frac{\partial \overline{U}_i}{\partial x_j} + \frac{2}{Ro}\varepsilon_{ijk}\Omega_j \overline{U}_k = -\frac{1}{\varrho_0}\frac{\partial \overline{\delta P}_i}{\partial x_i} + \frac{1}{Fr^2}\overline{\delta T}\delta_{3i} + \frac{1}{Re}\frac{\partial^2 \overline{U}_i}{\partial x_j \partial x_j} - \frac{1}{Re_K}\frac{\partial^2 \overline{U}_i}{\partial x_j \partial x_j}, \qquad 2.$$

where $Re_K = U_R L/K$ is called a "turbulent" Reynolds number. Now if $K = 10^4\nu$ is approximated as a constant, the term containing the $Re_K$ is much larger than the term containing the ordinary Reynolds number. Assuming that the prototype flow is turbulent and that the model flow is laminar, the scale ratio is of the order 1:$10^4$ m, and velocity of approach flow $U$ is the same order of magnitude in model and prototype, then,

$$(Re)_{model} \cong (Re_K)_{prototype}. \qquad 3.$$

Hence, similarity may be established by modelling a turbulent prototype flow by laminar model flow when the scale ratio is in order of 1: $10^4$. At such scales, many of the similarity conditions normally applied to the simulation of flow and dispersion over complex terrain cannot be satisfied. Nevertheless, acceptable agreement between laboratory and field dispersion measurements is reported by Cermak (1971, 1984).

## Conclusions

The review of simulation possibilities of small scale models (of order 1:$10^4$) in wind-tunnel revealed that there was performed only one approach to date: the laminar flow analogy. Thus, in order to simulate the Tušimice open-cut mine in environmental boundary layer wind-tunnel of Institute of Thermomechanics in Nový Knín the laminar analogy will be used.

## References

Abe, M., 1941: Mountain Clouds, Their Forms and Connected Air currents, Pt. II, Bull. Cent. Meteorol. Obs., Tokyo, v. 7, no. 3.

Cermak, J. E., 1971: Laboratory Simulation of the Atmospheric Boundary layer, AIAA J., vol. 9, p. 1746.

Cermak, J. E., 1984: Physical Modelling of Flow and Dispersion Over Complex Terrain, Boundary-Layer Meteorology, 30, p. 261-292.

Janour, Z., 2002: Visualisation method in air pollution investigation by physical modelling, The 10th Int. Sym. On Flow Visualisation, Kyoto, Japan.

Snyder W. H. 1981. Guidelines for fluid modelling of atmospheric diffusion. EPA office of Air quality, planning and standards, Research Triangle Park, USA, EPA-600/8-81-009.