NUMERICAL SIMULATIONS OF TRANSPORT OF AIR-POLLUTANTS IN THE EARTH'S ATMOSPHERE

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ABSTRACT

The Earth's atmosphere contains various gaseous substances and solid particles, which are emitted into it as a result of industry activities. The spreading of pollutants in the atmosphere occurs generally due to diffusion, convection and turbulence. These phenomena are closely connected with each other and determine the basic mechanisms of the mass, velocity and energy transport.

Various methods of research into a transport of pollution can be distinguished. Let us mention an experimental study of the atmosphere. On the basis of this method it was possible to derive empirical formulations of plume behaviour. These simple equations provide a fast solution of pollution-concentration distribution. However, it is impossible to isolate the factors which influence measurement conditions. Therefore, analysis of the results is difficult and these results, which are obtained in field campaigns, are limited to a set of meteorological parameters and topography. On the other hand, in laboratory research one can investigate an influence of various factors, which number is considerably limited due to insufficient technical possibilities.

In the meantime, mathematical modeling of physical phenomena becomes more and more popular, as computer techniques are developed. Computational science has emerged as a new branch in science complementing both experiments and theory. The basic idea of computer experiments is to simulate the physical behavior of complicated natural systems by solving an appropriate set of mathematical equations that are built on the basis of a physical model. A typical way for computer simulation is to develop a mathematical model, perhaps in the form of a set of differential equations and then to transform them to a discrete form than can be numerically treated. Numerical simulation is a way to solve the mathematical model of a particular physical system. Numerical simulations attempt to initiate the dynamic behavior of a system and to predict or calculate subsequent events.

During the conference, the results of two-dimensional numerical simulations of transport of gaseous air-pollutants will be presented. Pollution is emitted from the point emittor, like a chimney, into the Earth's atmosphere. In the research a model, which describes the two-dimensional dynamics of the air and air-pollutants with the set of hydrodynamic equations, is developed. Therefore, the model reproduces the propagation of pollutants really well [1-6]. The hydrodynamic equations are solved by modern numerical CLawPack code [5]. The code was adapted by setting initial and boundary conditions as well as introducing a procedure for numerical realization of emission and diffusion. Moreover, this model reflects an action of gravitational force as well as constant and linear wind.

The results of numerical simulations reveal a number of interesting phenomena such as complex profiles of the pollutants, plume development, action of the buoyancy force and influence of the air-resistance especially at the initial stage of the propagation. While a plume propagates, the Kelvin-Helmoltz instabilities occur. As a result, vortices are generated. Theses vortices considerably slow down the diffusion of the pollutants in the ambient air. Due to the vortices, the air-pollutants are transported into regions that are far away from the chimney.

The spatial and temporal profiles were analysed spectrally to obtain the wavenumber and frequency spectra. The results of this analysis show a frequency shift with the distance from the emittor. The frequency either increases or decreases with the distance x. This shift is a consequence of random scattering. The random field, that is self-generated by the medium as a result of the interaction between the emission and the horizontal wind, is associated with the mass density, velocity, and pressure as well as it depends on time and space. Such random field enhances spatial spreading of pollutants. These results reveal the wavy character of the propagation.

All of the numerical results which are a subject of presentation show qualitatively the expected phenomena that take place both in the neighbourhood of and farther out from the chimney. A qualitative comparison will be provided.

REFERENCES

1. Michalczyk J.K., Murawski K., Pawłowski L., 1999: Propagation of pollutants in the atmospheric air – study by numerical simulations, Protection of the Air And Problems of Waste, 2, 50-53, in Polish
2. Michalczyk J.K., Murawski K., 1999: Numerical modeling of continuous emission of the air pollutants, Protection of the Air And Problems of Waste, 6, 211-218, in Polish
3. Michalczyk J.K., Murawski K., 2001: Numerical simulations of air-pollution dispersion in the atmosphere, Protection of the Air And Problems of Waste, 5, 175-185, in Polish

4. Murawski K., Michalczyk J.K., 2001, Numerical simulations by Godunov-type schemes of air-pollutants dynamics, TASK Quarterly, 5, 2, 207-228
5. Michalczyk J.K., Murawski K., 2002, Numerical simulations of air-pollutants in windy atmosphere, TASK Quarterly, in press
6. Michalczyk J.K., Murawski K., Numerical simulations of air-pollutants in a gravitationally stratified atmosphere, Journal of Theoretical and Applied Mechanics, reviewed
7. LeVeque R.J., 1997: CLAWPACK User Notes, Applied Mathematics, University of Washington, Seattle, Washington