Analysis of turbulent flows with dispersed phase: impact of two-way momentum coupling and gravity on particle statistics

In the natural environment, we commonly observe the continuous motion of air masses that transport cloud droplets, ice crystals or snowflakes. A well-known, growing problem is the presence in the atmosphere of dust and smog. The source of these pollutants is the so-called low emission. Even desert sandstorms or wind-driven volcanic ashes can sometimes affect the weather in our climate zone. In turn, the flow of liquids in water reservoirs, seas and oceans is often accompanied by the transport of fine suspensions or sediments. Liquid droplets and solid particles of size below one millimeter are commonly called particles. The flow of liquid or gas often has a complex and disordered nature, known as turbulent or chaotic. For this reason, the mathematical description faces significant difficulties and the computations are very expensive. Therefore, to quantify the processes the fastest computing machines currently available are used. Particle transport by a turbulent fluid is also an important mechanism for many technological processes. They find numerous applications in industry and other fields related to the power engineering and motorization. Examples of these include: efficient combustion of pulverized coal in boilers, pneumatic transport in pipelines, combustion of fuel-air mixture in engines, filtration of solid particles (soot, ashes) from exhaust gases, or spraying of fertilizers and plant protection agents.

The goal of the project is to develop computational methods for modeling particle flows. In particular, the method should faithfully represent different situations in which particle collide and possibly merge/coalesce.

The motion of particles depends also on the gravitational acceleration. Moreover, in turbulent flows we observe clustering of particles in space, which affects the collision rate and the velocity of their settling. In addition, turbulence affects the strength of aerodynamic (hydrodynamic) interaction between the individual particles and between the particle clusters. Despite many years of research and rich scientific literature containing results from observations and measurements, the quantitative description of these mechanisms remains incomplete. Experimental studies are usually difficult, because these flows span a wide range of spatial and temporal scales. Furthermore, the measuring devices have technical limitations and do not allow to simultaneously measure the 3D particle position and velocity. When it comes to cloud processes, the additional difficulty is to perform measurements directly in clouds. Remote measurements with the sensing radars usually do not yield desired accuracy. For this reason, computational methods are of help. In this project, we will employ advanced computers with many processors to develop mathematical models of the particle transport.

An important goal of our research will be taking into account the effect of turbulence modulation by particles. Such effect is apparent when the mass of particles contained in the fluid is sufficiently large, while their volume remains small. We developed an advanced numerical code, which will be extended by a module that allows to represent this effect. An additional part of the project will be the evaluation of the impact of small vortical structures on the particle motion. In modeling of large-scale flows or flows in devices with complex geometry, such structures cannot be explicitly represented.

A thorough analysis of mechanisms of the turbulent transport is an important scientific task. The knowledge obtained from this research can contribute to improvement of other computational tools employed in the averaged scale. This will lead to better controlling of the aforementioned industrial processes, enable their optimization, design of new devices and - which is important for all of us - development of more accurate weather forecasts by more precise prediction of precipitation formation from cloud drops or ice crystals.