Experimental and Numerical Investigation of Particle Precipitation in a Symmetrical Double Cyclone Separator

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Abstract

Disperse multiphase flows are very common for processes in mechanical and thermal process technology (e.g. gas–particle or gas–droplet flows, coal combustion, pneumatical conveying, erosion phenomena). Furthermore processes for the separation of solid particles from gases or fluids and for the classification and particle size analysis are an important field of interest in process technology.

The paper deals with the experimental and numerical investigation of the particle precipitation in a special class of cyclone separators, the so called symmetrical double cyclone separator (see fig. 1). The cyclone shown in fig. 1 was developed by the *Gesellschaft für Luft– und Umwelttechnik mbH, Eckernförde/Germany* (LUT ltd.). By using this type of cyclone the secondary flow along the lid, which is observed in standard cyclones, can be avoided. In the case of a secondary flow along the lid small particles can move directly from the inlet to the clean gas exit bypassing the main vortex flow in the conical part of the cyclone. The diagonal secondary flow induced by the walls of the conical parts of the symmetrical double cyclone leads to enrichment of the particle phase along the walls. The secondary flow is led to the walls of the sedimentation chamber by special shielding or guiding equipment attached at the lower end of the conical part of the cyclone to the outer diameter of the vortex finder tubes. In this flow region along the walls of the sedimentation chamber also smaller particles are able to agglomerate and to sedimentate as larger agglomerates in the sedimentation chamber.

In comparison with conventional cyclone separators and other kinds of special cyclones better particle precipitation can be achieved with this special type of a symmetrical double cyclone separators. This means that the cut–off particle diameter d_{50} for the particle precipitation rate $T(d_P)$ (with $T(d_P = d_{50}) = 0.5$) can be significantly decreased. The particle diameter d_P and d_{50} used in this paper are the so called "aerodynamical" particle diameter commonly used in aerosol technology and corresponding to a difference in particle to fluid density of $\Delta\rho = 1000\ kg/m^3$. For a diameter of the separation chamber of the cyclone of 40 mm a cut–off particle diameter d_{50} of less than 100 nanometers has been measured. Even for diameters of the separation chamber of about 200 . . . 250 mm values for the cut–off particle diameter d_{50} less than 1 μm could be measured [9, 1, 10].

Experiments described in this paper were carried out at the Flensburg University of Applied Sciences. In a series of experiments a symmetrical double cyclone separator with a diameter of the separation chamber of 230 mm has been investigated. Particles have been dispersed with the RBG 1000 and the particle size measurements have been carried out using the particle sizer PCS 2000, both made by the PALLAS GmbH, Karlsruhe/Germany. For the particle phase calcium carbonate particles were used, produced under the trading name OMYACARB 2–GU by OMYA GmbH, Köln/Germany. So the particle phase used in the experiments for investigation of particle precipitation in the symmetrical double cyclone separator can be characterized by the mean particle diameter $d_{50,3}$ of the distribution sum $Q_3(d_P)$ of about 2.5 μm which corresponds to an aerodynamic diameter of about 4.1 μm.

The experimental results for the particle precipitation rates in the symmetrical double cyclone have been compared with numerical predictions for three different variations of the cyclone geometry. For these numerical simulations a 3–dimensional Lagrangian approach developed by Frank et al. [2, 3, 4, 5] was used. The numerical method is based on the modified Navier–Stokes solver FAN–3D [7, 8] which is able to calculate 3–dimensional, steady, incompressible flows in complex geometries using non–orthogonal, boundary fitted, block–structured numerical grids. Due to the complex flow geometry of the investigated cyclone separators numerical grids with up to 95 different grid blocks and about 350.000 grid cells had to be designed for the numerical calculations of the gas–particle flow.

The disperse phase is treated by the Lagrangian approach where a large number of particle trajectories is calculated throughout the flow domain. For the formulation of particles equation of motion a small density ratio ρ_F/ρ_P is assumed. So the drag force, the lift force due to fluid shear (Saffman force), the pressure force, the gravitational and added mass force are taken into account [4, 5]. Particle precipitation rates were obtained from the calculation of about 10.000 particle trajectories with a particle diameter distribution in the range of $d_P = 0.6 \ldots 20.0\ \mu m$ and by analyzing the number of particles reaching the particle hopper vs. the number of particles reaching the clean gas exit.

The numerical investigations for the precipitation of limestone particles ($\rho_P = 2700\ kg/m^3$) were carried out for three different geometrical configurations of the symmetrical double cyclone using a constant gas inlet velocity of $u_F = 25\ m/s$. In a first numerical simulation the influence of the gap width between the apex cone and the inner cyclone wall on the particle precipitation rate has been investigated. In a second numerical experiment the spiral inflow into the cyclone main body has been changed to a tangential inflow.

The numerical flow simulations confirm the expected main vortex flow structure known from cyclone theory and from experimental observations. The numerical predictions especially confirm the substantial contribution for particle precipitation of the recirculation of a certain gas volume flow rate from the cyclone main body through the gap at the apex cone into the particle hopper. The obtained numerical results for the particle precipitation rates are in good agreement with the experimentally predicted precipitation rates.

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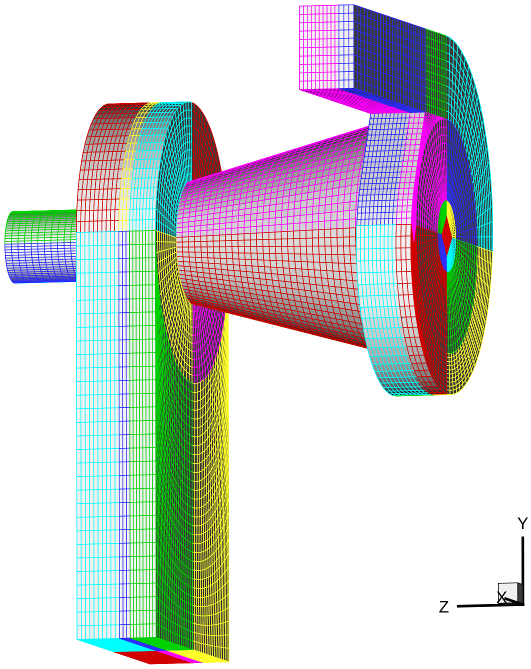

Figure 1: Grid structure for the symmetrical double cyclone (left half).

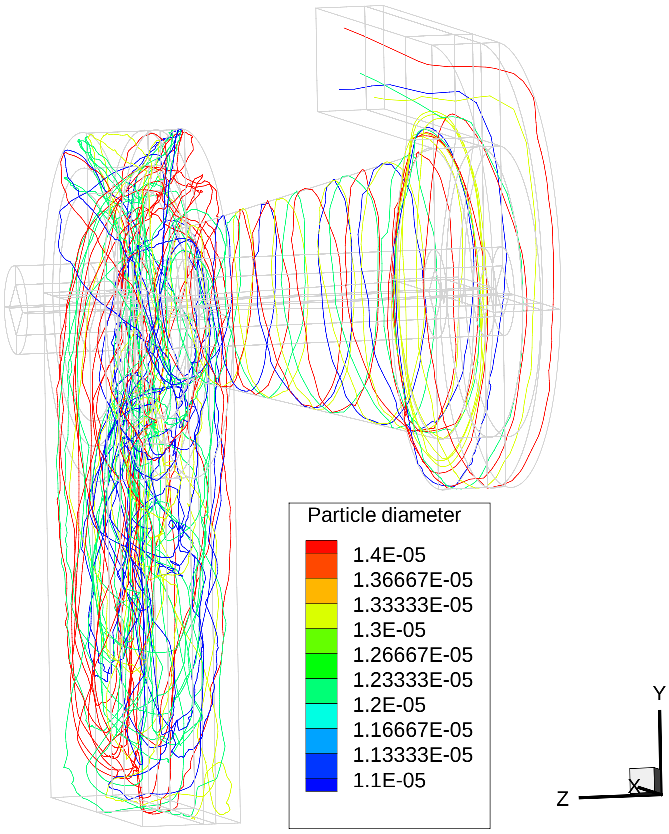

Figure 2: Trajectory calculation for the symmetrical double cyclone (left half).