MATEMAATIKA-LOODUSTEADUSKOND
MITMEFAASILISTE KESKKONDADE FÜÜSIKA TEADUSLABORATOORIUM
TEADUS- JA ARENDUSTEGEVUSE AASTAARUANNE 2013

1. Struktuur

Mitmefaasiliste keskkondade füüsika teaduslaboratoorium, juhataja Ülo Rudi
Research Laboratory of Multiphase Media Physics, Head of laboratory Ulo Rudi

2. Teadus- ja arendustegevuse (edaspidi T&A) iseloomustus

2.1. **Uurimisgrupi nimetus**:Aerosoolsete kanal-, gradient-ja keerisvooluste teoreetiliste aluste loomine ning rakendused tehnoloogilistes protsessides, uurimisgrupi juht Aleksander Kartušinski, DSc.

Research group: Development of the theory of the particulate channel, shear and vortical flows and its practical application in technologies, leader of the research group Aleksander Kartushinsky, DSc.

2.1.1 Uurimisgrupi teadustöö kirjeldus. The description of research.

1. The main objective of the research of the flows is to develop 3D complete mathematical model for numerical simulation of the turbulent particulate flows in pipes and channels, jets and shear flow. The model considers 3D tangential motion and 3D rotational motion of a carrier (fluid) and particulate phases together with the four-way coupling which comprises the effect of the particles collisions. The modeling is mainly based on the RANS mathematical method and develops the theory of a free and wall-bounded particulate flows as well as the particles deposition onto various surfaces.
2. The second task of the research group is to develop the analytical and numerical modeling of the vortex ring-like structures. The asymptotic analysis, entrainment diagram method and direct numerical simulation are applied for analyzing the structural features of these types of a vortex flow. For investigation of the mixing and transport inside the starting vortex flows the Lagrangian method is applied.
3. In order to validate the results obtained by the theoretical models, the laboratory applies the test rig based on the horizontal channel to generate the turbulent gas and gas-solid particles flows, including the grid-generated turbulent flow, the velocity shear flow, the free jets and the wall-bounded flows, and different measuring equipment, such as Dantec Dynamics Flow Explorer laser Doppler anemometer for the high-precision measuring of velocity and fluctuating velocity of gas and particles, 2D 15Hz particle image velocimeter (PIV) and 10KHz particle tracking velocimeter (PTV), which allow to measure the instantaneous velocities of gas and particles and produce 2D velocity vector fields as well as the particles mass concentration.

2.1.2 Põhilised teadustulemused 2013. aastal. The main scientic results in year 2013

1. Numerical modeling of the turbulent dispersion of glass particles occurring in linear shear flow and grid-generated flow has been carried out by joined three 3D approaches: Reynolds averaged Navier-Stokes, Reynolds stress turbulence and probability density function models. Cross-sectional distribution of concentration of particles ejected from a point source expanded downstream and filled completely the flow cross-section. The rate of this expansion allowed calculating the turbulent diffusion for above-mentioned types of flow. The numerical results agreed satisfactorily with the experimental data obtained in the Laboratory.

(Papers 1, 7).

2. 3D Reynolds stress turbulence model has been elaborated for horizontal and vertical turbulent particulate flows in rectangular channels with smooth and rough walls. The model was used to simulate vertical grid-generated turbulent particulate channel flow. Both, enhancement and attenuation of turbulence have been considered by means of additional terms of transport equations of normal Reynolds stress components. This allowed carrying out calculations covering long distance of the channel length without using algebraic assumptions for various components of the Reynolds stress. (Papers 1, 4).

3. Numerical model has been elaborated for deposition of corundum particles onto horizontal flat plate within laminar boundary layer in a free-stream moderate turbulent flow. The model considered deposition onto the surface to be probabilistic process determined both by hydrodynamics and adhesive behavior of particles and surface. The model has been based on two-fluid approach applied for a carrier gas and particulate phase. We have revealed that gravity and lift forces have decisive influence on behavior of solid particles taken place within the laminar boundary layer and on their deposition expressed via the distributions of the particles transverse velocity and mass concentration. These effects become more pronounced for larger particles. This fact, coupled with the higher probability of entrainment by the surface, results in their larger deposition velocity.(Paper 3)

4. The previously developed model for viscous vortex ring is generalized to take into account ring's confinement and deformation of ring's core. Confined vortex ring dynamics have not been previously studied despite their occurrence within biological and industrial flows. It is found that the prediction of the new analytical model for translational velocity agrees with values predicted by numerical analysis for small Reynolds numbers. The values of translational velocity are shown to be smaller than those predicted for an unconfined vortex ring. Also, the effects of the confinement and ellipticity of vortex ring's core on the formation number for an optimal vortex ring are studied. It is shown that confinement and compression of vorticity increases the formation number. As well as it is shown that the predicted drift velocity of the vortex ring with elongated vortex ring's core differ from that predicted by Rott-Cantwell decaying law at large times, but is closer to experimental data compared with the predictions of the latter law.(Paper is presented to the Journal of Fluid Mechanics, 2014)

5. A new approach to numerical simulation of two-phase flows, based on a combination of full Lagrangian method for dispersed phase and mesh-free vortex blob method for carrier phase has been suggested. In this case, the problem of calculation of all parameters in both phases (including particle concentration) was reduced to the solution of a high-order system of ordinary differential equations, describing transient processes in both carrier and dispersed phases. This allows to study local zones of particle accumulation in complex transient flows in detail, including those with multiple intersections of particle trajectories and the formation of 'folds' in concentration field of dispersed phase. Two processes have been modeled by the new approach: the time evolution of a two-phase Lamb vortex and the development of an impulse two-phase jet, leading to formation of a vortex ring-like structure. These examples involve the formation of local zones of particle accumulation and regions of multiple intersections of particle trajectories. These features of the flow cannot be simulated using conventional Eulerian and Lagrangian methods described in literature.

6. Within grant ETF 9343, the numerical modelling of particulate turbulent upward flows has been fulfilled where effect of the inter-particles collision has been analyzed along with other impacts. The studied flow was considered as a freeboard part of CFB flow domain and it was found the for higher mass loading up to 10 kg dust/kg air the particles were modified turbulence that eventually resulting in change of average velocity of the carrier gas-phase flow and thus all other flow parameters (In paper Kartushinsky, A., Rudi, Y., Shcheglov, I., Tisler, S. and Krupenski I. Chapter: RANS numerical simulation of turbulent particulate pipe flow for

fixed Reynolds number, book “Computational and Numerical Simulations”, ISBN 980-953-307-1115-4, edited by Jan Awrejcewicz. 2014.).
Kartushinsky, A., Rudi, Y., Shcheglov, I., Tisler, S. and Krupenski I. Chapter: RANS numerical simulation of turbulent particulate pipe flow for fixed Reynolds number, book “Computational and Numerical Simulations”, ISBN 980-953-307-1115-4, edited by Jan Awrejcewicz. 2014.

2.1.3 Uurimisgrupi olulisemad publikatsioonid

1. Kartushinsky, A.; Rudi, Y.; Stock, D.; Hussainov, M.; Shcheglov, I.; Tisler, S.; Shablinsky, A. (2013). Numerical simulation of particulate grid-generating turbulence by 3D RSTM. Proceedings of the Estonian Academy of Sciences, 62(3), 161 – 174.
2. Kartushinsky, A.; Rudi, Y.; Tisler, S.; Shcheglov, I.; Shablinsky, A. (2013). Numerical study of upward particulate pipe flows at constant Reynolds number. Proceedings of the Estonian Academy of Sciences, 62(2), 97 - 108.
3. Kartushinsky, A.; Hussainov, M.; Michaelides, E.E.; Rudi, Y.; Shcheglov, I.;Tisler, S.; Krupenski, I. (2013). Particles deposition at horizontal flat plate in turbulent particulate flow. Canadian Journal of Chemical Engineering, 92 (1), 1 - 12
4. Kartushinsky, A.; Rudi, Y.; Stock, D.; Hussainov, M.; Shcheglov, I.; Tisler, S. (2013). 3D RANS-RSTM numerical simulation of channel turbulent particulate flow with wall roughness. 11TH INTERNATIONAL CONFERENCE OF NUMERICAL ANALYSIS AND APPLIED MATHEMATICS 2013: ICNAAM 2013, Rhodes, Greece, 21–27 September 2013. (Toim.) T. Simos, G. Psihoyios, Ch. Tsitouras. Amer Inst Physics, 2013, (AIP Conference Proceedings; 1558).
5. Sazhin, S; Boronin, S; Begg, S; Crua, C; Healey, J; Lebedeva, N; Osiptsov, A; Kaplanski, F; Heikal, M. (2013). Jet and Vortex Ring-Like Structures in Internal Combustion Engines: Stability Analysis and Analytical Solutions. In: Procedia IUTAM : IUTAM Symposium on Waves in Fluids: Effects of Nonlinearity, Rotation, Stratification and Dissipation, Moscow, June 18-22, 2012. Elsevier, 2013, 196 - 204. 3.1.
6. Kartushinsky, A.; Rudi, Y.; Tisler, S.; Shcheglov, I.; Shablinsky, A. (2013). Numerical simulation of upward particulate pipe flows at constant Re. Proceedings of the 8th Internatinal Conference on Multiphase Flow (ICMF 2013),Jeju, Korea, May 26-31, 2013. Paper No 042.
7. Kartushinsky, A.; Rudi, Y.; Stock, D.; Hussainov, M.; Shcheglov, I.; Tisler, S.; Shablinsky, A. (2013). Reynolds stress turbulence model for particulate grid-generated turbulence. Proceedings of the 8th Internatinal Conference on Multiphase Flow (ICMF 2013),Jeju, Korea, May 26-31, 2013. Paper No 041.

2.2 Laboratooriumi töötajad, kes on välisakadeemiate või muude oluliste T&A-ga seotud välisorganisatsioonide liikmed.

Ülo Rudi, ajakirja Oil Shale nõustajate kogu liige; ajakirja Polityka Energetyczna (Energy Policy Journal, Poola Teaduste Akadeemia.) toimetuskolleegiumi liige; International Centre on Energy and Environment Policy liige; kirjastuse Elsevier ajakirja „Energy Policy“ retsensent.

Aleksander Kartušinski, Euroopa Liidu COST programmi projekti 1106 juhtkomitee liige; Euroopa Mehaanikanõukogu EUROMECH liige, ajakirjade Turbulence and Combustion, International Journal of Heat and Mass Transfer, Journal of Fluids Engineering, Physical Review & Research International, ASME Journal of Fluids Engineering, retsensent.

Feliks Kaplanski, Euroopa Mehaanikanõukogu EUROMECH liige, ajakirjade Physics of Fluids, J. Fluid Mechanics, TCFD, Turbulence and Combustion, FDR and reviewer of the European Mathematical Information Service (EMIS)

Sergei Tisler, Euroopa Liidu COST programmi projekti 1106 juhtkomitee liige.