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# Dispersed multiphase flows: advances in measuring, simulation and modeling

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Dispersed multiphase flows are commonly encountered in a wide variety of natural and industrial applications, from sedimentation in rivers and plankton surfacing in oceanic flows to fluidized bed in chemical reactors and pneumatic conveying systems. In these flows, a dispersed phase (consisting of particles, droplets and/or bubbles) is transported by a carrier phase. The interaction between the phases results in complex dynamics (e.g., transport, spatial clustering, and deformation or break-up) that is rich in physics and poses a wide spectrum of theoretical, computational, and experimental challenges. These challenges are at the very core of the research efforts made by the multiphase flow community over the past decades.

Our motivation to publish a special issue focused on some of the recent advances in the measuring, simulation, and modeling of dispersed multiphase flows, arose during the 1st BICTAM-CISM Symposium "Dispersed Multiphase Flows: from Measuring to Modeling", which was co-organized by Beijing International Center for Theoretical and Applied Mechanics (BICTAM) and International Centre for Mechanical Sciences (CISM) in 2021. Due to the restrictions imposed by the Covid-19 pandemic, the symposium was held as a virtual event from March 2, 2021 to March 5, 2021. More than 70 experts and scholars from 12 countries, including China, Italy, France, Sweden, Spain, Austria, Germany, Israel, Japan, Poland, the Netherlands, and the United Kingdom, attended the Symposium, which also attracted over 1100 live streaming views from 23 countries around the globe. The participants came from rather diverse fields of research in the field of dispersed multiphase flows, and their contributions ranged from curiosity-driven research on peculiar phenomena to investigations addressing industrial needs. This allowed to cover nicely the recent progress made in research, development, standards, and applications of the topics related to dynamics of particles, bubbles, and droplets in isotropic and wall-bounded turbulence; rigid and deformable particle suspensions; non-Newtonian dispersed flows; reactive dispersed flows; advances in measurement and simulation techniques; modeling of collision, agglomeration and fragmentation/breakage phenomena, among others.

We, as the symposium organizers, appreciated the benefits of bringing together scientists concerned with such diverse aspects of dispersed multiphase flows, irrespective of their driving motivation and independent of their approach, be it experimental, numerical or theoretical. We thus found it timely to make a collection of current research achievements in the field available to a wider audience. After the symposium, invitations were sent to several research groups with a well-established activity in the field to contribute a paper to this special issue of *Acta Mechanica Sinica*. To our great pleasure, almost all of the invitees were able to accept the invitation and submitted their works in the late fall/winter of 2021. All manuscripts were then subject to evaluation by anonymous reviewers as per the regular publication procedure of the journal. Altogether, 9 reviewed and revised papers are published in this special issue. The papers focus on the different physical, modelling, and measuring issues emerging when examining the behavior of dispersed multiphase flows. Given the variability in the methods employed in the various investigations, but also in the type of dispersed phase and turbulent flow considered in the different papers collected in this special issue, a brief survey is provided next in which the various contributions are organized in accordance with the approach used.

## 1. Modelling

In the first paper of this special issue [1], the turbulent

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modulation induced by the presence of an interphase force for interfacial and fluid-particle flows is investigated both analytically and numerically, for the case in which surface tension and drag define the interphase coupling. The study shows that surface tension and drag contribute as additional production/dissipation terms in the transport equation for the turbulent kinetic energy.

A different modelling aspect is tackled in Ref. [2], where a new a fast-mapping method is proposed to evaluate the immersed boundary hydrodynamic force exerted on the particle surface, considering both spherical and non-spherical (ellipsoidal) particles and showing the effectiveness of the method for the case of moving particles.

The study by Wacławczyk [3], on the other hand, provides a comprehensive review of the differences between the deterministic (sharp and diffuse) and statistical models of the interphase region between the two-phases, showing that a suitably-derived statistical model of the mesoscopic intermittency region can be successfully used to predict equilibrium and non-equilibrium two-phase flows by means of numerical simulations.

Finally, Li and Lin [4] examine the motion of small particles in confined shear flow of viscoelastic fluids, looking at the issues associated with the ability to correctly reproduce features such as the lateral equilibrium position of the particles, the interaction and aggregation of multiple particles as well as the chain structure that they form, or the motion of non-spherical particles.

## 2. Experiments

The only experimental study [5] proposed in this special issue addresses the problem of the motion of a spherical droplet in a plane traveling sound wave. The study confirms the theoretical results from the wave equations in the long-wavelength regime (when the particle size is much smaller than the wavelength) and extends the assessment to a wider parameter range (e.g., the particle-fluid density ratio, which is of specific importance in practical applications) relative to particle motion in unsteady fluids.

## 3. Simulations

Nowadays, simulations aimed at reproducing with high fidelity airborne virus emissions by respiratory events are becoming a standard. In Ref. [6], the cloud dispersion produced by a violent expiratory event is simulated by means of unsteady compressible Reynolds-averaged Navier-Stokes based (RANS-based) computational fluid dynamics (CFD). The study demonstrates that unsteady RANS (URANS) equations are capable of reproducing the general features of the flow hydrodynamics and provide decent estimates of the aerosol cloud dispersion in spite of the complex and transient nature of the flow, characterized by a laminar-to-turbulent regime transition during air injection and by a rapid turbulence intensity decay at the end of the exhalation phase.

The study performed by Romanò [7] considers the problem of reconstructing the velocity field for a particle moving near a singular corner, and is aimed at demonstrating that a robust reconstruction of the particulate phase space is possible even for singular flows, at least for the case of neutrally-buoyant particle. This provides a tool for the correction of sedimentation effects starting from the trajectory of density-mismatched particles and deriving the flow for a neutrally-buoyant particle all over the domain.

In Ref. [8], a three-dimensional direct numerical simulation (DNS) with complex chemistry is employed to examine the statistical behavior of the turbulent kinetic energy and of the enstrophy in turbulent premixed flames at varying Lewis and Karlovitz numbers, spanning both the thin and the broken reaction zone regimes and looking at devising suitable scaling laws.

Finally, the special issue features a review paper [9] that surveys recent simulation results on the translational and orientational dynamics of small gyrotactic swimmers in turbulence, focusing on the effect of gyrotaxis on preferential concentration phenomena such as patchiness and clustering, as well as preferential orientation phenomena associated with vertical migration.

## 4. A brief outlook

Almost all the investigations reported in this special issue benefited from the substantial advances in recent years, either in optical measurement techniques and accompanying computerized data acquisition or in highly resolved computer simulations exploiting the steady increase in efficiency and speed of high-performance computers. The articles in this issue are a small and yet representative collection of research activities in this area, covering different methodological aspects and allowing now physical insights and technical developments. This collection, albeit not at all exhaustive of all the current studies in this field, demonstrates the enormous potential for thorough investigations of various aspects of dispersed multiphase flows from a variety of different viewpoints. The present status, as reported herein, is most likely only the beginning of further advancements in the exciting field of dispersed multiphase flow behavior and a variety of intriguing physical phenomena associated with the departure from dilute flow conditions and point-particle approaches.

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