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Basic Concepts and Scope of the Book

The topic of multiphase flows is essentially a subcategory of fluid dynamics that deals with gases and liquids in motion. Fluid dynamics can therefore be a study of waterfalls, the swirling air in a tornado, exhaust gases in a rocket engine, natural gas flow in a pipeline between an offshore platform and land, ocean waves, and so on. In other words, one can imagine thousands of examples from nature and industry.

In this book, we talk about *multiphase flows*. This refers to an investigation of a flow where there are at least two *phases* (i.e., gas, liquid, solid) simultaneously. We may consider flows of gas with solid particles (e.g., volcanic gases with ash), liquid with a solid phase (e.g., study of a landslide), gas with liquid droplets (e.g., air with raindrops in a thunderstorm), and many others.

The fascinating issue is that scientists still have not solved this type of problem due to its enormous complexity. The researchers try to exploit various tools to understand, describe, and model the multiphase flow phenomena. They use laboratory experiments, computer simulations, and just pure theoretical analysis.

It is not intended to cover all the potential aspects of multiphase flows in the present book. The objective is to limit the topic to a system consisting of *solid particles in fluids*. This can be illustrated in the top drawing of Figure 1.1 representing a flow laden with particles. The figure also shows the main steps of the 'algorithm' that the book is based on.

Firstly, in Chapter 2, we investigate the simplest possible case, which is a flow of a *single* particle in a fluid (denoted as *particle–fluid interactions* in Figure 1.1). In other words, we neglect the presence of the other particles yet. The particle is subjected to a fluid flow, and we study the forces that the particle experiences.

Most readers are probably aware of the drag force, the most well-known example of the particle–fluid interaction. This force results from the velocity difference between the fluid and particle but also depends on the fluid density, viscosity, and particle size. In this book, we investigate how this force is derived, and we analyse

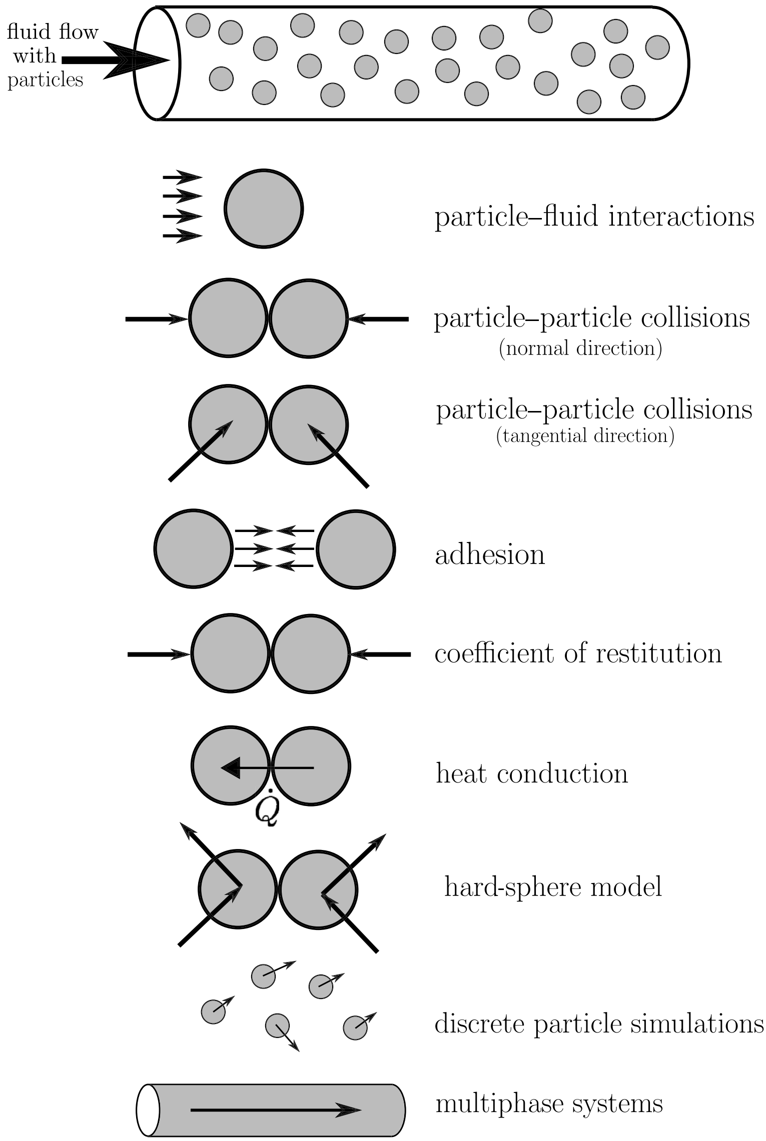

Figure 1.1 The scope of the book.

the mathematical models that can be used to compute it. This knowledge is essential later if one wishes to know the particle's behaviour, that is, its motion.

Nevertheless, Chapter 2 also covers other interactions such as lift forces that occur when the particle rotates or is immersed in a flow whose velocity field in not uniform. Thus, we investigate the so-called Magnus and Saffman force. In addition, we consider perhaps less-known interactions such as Basset and added mass force.

Finally, we look into problems that can only be explained on the molecular level of the surrounding fluid: Brownian motion, rarefied flows, and thermophoretic force. These interactions are often crucial for tiny particles, such as nanoparticles.

In the end, Chapter 2 also covers *heat effects*, where we discuss the issue of the temperature differences between the particle and fluid. Many readers will find the topic familiar as it touches on fundamental heat transfer problems.

In the next chapter (Chapter 3), we broaden the previous analysis to *two particles* close to each other (denoted as *particle–particle collisions* in Figure 1.1). In this chapter, we pay attention to a case where two spherical particles are subjected to head-on collisions, that is, they collide along the normal to the plane of impact.

As the chapter concentrates on solid bodies in contact, it starts with an introduction to contact mechanics, with the complete derivation of the so-called Hertz theory. Thus, this book differs also from the other texts on multiphase flows or particle technology that focuses less on this problem. Later, we extend the issue of contact mechanics to presenting the full collision dynamics, which solves the whole process of the impact as a function of time. First, attention is paid to elastic deformation and later dissipative forces by showing various models of particle–particle collisions.

It is also interesting to note that the last sections of Chapter 3 cover plastic deformation with a complete derivation of mathematical models. In this manner, the book differs significantly from similar available texts on multiphase flows that seldom touch on this aspect.

Chapter 4 resembles Chapter 3, since it also focuses on particle–particle contacts. Nevertheless, it considers a *tangential contact*, that is, we extend the previous discussion to a more complex case: not necessarily head-on collisions. Also similarly to the previous chapter, contact mechanics is first addressed with a detailed analysis of the forces acting between the bodies. Later, the problem of collisions is introduced with the presentation of the entire collision dynamics process again.

The phenomenon of particle–particle interactions is described even more in Chapter 5 by allowing for the *adhesion* between the particles, that is, their attraction. We start with the basic physical explanation of the forces between two surfaces close to each other. This is later gradually extended by a detailed derivation of two main theories, Johnson–Kendall–Roberts and Derjaguin-Muller-Toporov (JKR and DMT), used in the field of adhesive contact mechanics. The derived mathematical relations are again used for investigating a particle–particle collision.

In this way, Chapters 2–5 show the reader how to gradually implement a collision process in a multiphase flow from a very simple case to an increasingly complex situation. Many of the topics are illustrated with worked examples, as well as ready computer codes that the reader can exploit in their further research.

An important concept when modelling two-phase flows is the so-called *coefficient of restitution* that accounts for the mechanical energy loss during a collision. This coefficient is relatively straightforward to understand, measure, and use in practice. Therefore, Chapter 6 is entirely devoted to this topic. It is shown how this coefficient is related to the previous chapters of the book and how it can be often analytically derived using the presented mathematical models.

The next chapter, Chapter 7, constitutes a spin-off from the aforementioned algorithm. It aims at *heat conduction* between two particles of different temperatures in physical contact during a collision. During the contact time, the particles transfer heat, and its quantification is considered in the chapter. As previously, main mathematical models are presented or derived. Also, the objective is to repeat some of the relations mentioned in the previous chapters, although the aim is somewhat different.

Chapters 3–6 formulate an approach that is often referred to *soft-sphere model* of collisions. This modelling technique exploits ordinary differential equations describing the course of collision in time (from the first contact until the bodies bounce off). This strategy made it possible to look into the particle deformation, velocity, acceleration, and inter-particle forces. However, in Chapter 8, we change the strategy.

Chapter 8 pays, namely, attention to the *hard-sphere model*, which is another approach to studying collisions between particles. This model does not use differential equations like the previous model. Instead, the hard-sphere model is based on investigating the impulse-momentum expressions that relate the particle states before and after the collisions. Then, we avoid exploring the whole collision dynamics, which is computationally expensive and requires numerical solving of the differential equations.

Thus, Chapter 8 inspects a robust and elegant approach that can significantly reduce the computation time. It is interesting to note that this kind of model is rather seldom addressed in the research literature or texts on multiphase flows. Therefore, the objective of this chapter is to give a detailed analysis with complete derivations.

Finally, Chapter 9 concludes the whole algorithm by introducing a system of many particles in a fluid (denoted as *discrete particle simulations* in Figure 1.1). The particles move in the system driven by forces (as introduced in Chapter 2). Also, they may collide where the interaction can be modelled using the knowledge either from Chapters 3–6 (the soft-sphere approach) or alternatively from Chapter 8 (the hard-sphere approach). In addition, the modelling can also involve heat conduction between the particles, as shown in Chapter 7.

The last chapter of the book (Chapter 10) constitutes a collection of various issues devoted to *multiphase systems* as a whole. In the chapter, we consider some selected aspects: particle concentration, the mean distance between them, suspension viscosity, turbulent dispersion, preferential concentration, particle size distribution, collision frequency, and flow through a bed of particles. Thus, this chapter is not directly related to the previous topics and can be read independently.

This book does not cover all the possible topics within the multiphase flow. Some important aspects such as the Eulerian approach for the flow description or population balance model are missing, as they are very detailed and depicted in the other texts, especially in Gidaspow (1995) and Ramkrishna (2000). Thus, the book is intended to investigate flows of individual particles, that is, the so-called *Lagrangian approach*, alternatively *discrete element method* or *disperse particle simulations*. Also, less attention is paid to non-spherical or wet particles in gases, although these topics are crucial in many applications. Finally, the present text is not dedicated to erosion caused by colliding particles, as there exist books only covering this issue.

As noted earlier, this book frequently supports its theory with practical demonstrations through worked examples. However, readers are also encouraged to explore the accompanying website, multiphasebook.com. On this site, they can access further exercises and discover additional remarks, including errors brought to light by other readers.