Abstract

The main focus of this thesis is to study the heat transfer in non-isothermal turbulent particle-laden flows. Numerical and theoretical tools are used to better understand this non-trivial multi physics and multi-scale problem. Several aspects of such complex problem have been observed in order to discover, formulate and quantify the role of inertial heavy particles in heat transfer within a turbulent unbounded shearless flow. For this reason, a basic flow configuration has been considered to mimic a small part of the real-world physical domain e.g. a small portion of warm cloud in atmosphere. Numerical results have been obtained from the direct numerical simulations (DNSs) within the valid range of point-particle (PP) Eulerian-Lagrangian (EL) approach. In the first part, the theoretical background is introduced which consists of the governing equations for the carrier flow and discrete phase. In the second part, the numerical method and the limits and assumptions which have been used throughout this study, are discussed. In addition, statistics of temperature and heat flux computed by DNS are provided and discussed at different flow conditions in terms of flow parameters. Two main sets of numerical results are provided and evaluated in order to cover a wide range of physical problem in which the research objective can be addressed by varying the carrier flow Taylor micro-scale Reynolds number (from 37 to 124) and particle Stokes number (from 0.1 to 6) and thermal stokes number (from 0.1 to 10). The effect of particle inertial, thermal inertial, carrier flow Taylor microscale Reynolds number, particle thermal back-reactions in collisionless and collisional regimes are evaluated and discussed at a fixed particle volume fraction, particle-to-fluid density ratio and fluid Prandtl number. A novel decomposition is also proposed to reveal the mechanisms behind the modification of temperature statistical moments and velocity-temperature correlation in terms of fluid velocity and temperature correlation and particle acceleration and temperature time derivative statistics. In the third section, we use kinetic theory to formulate a kinetic-based probabilistic framework to describe the non-isothermal particle-laden

turbulent flow. This approach allows us to derive macroscopic field equations for the discrete phase by utilizing the single-particle probability density function (pdf). The transport equation of this pdf is also derived to investigate the dynamical and thermal behavior of inertial particle in the phase space by looking at the unclosed statistical moment within the pdf evolution equation. Most important moment, particle temperature time derivative conditional on particle position, velocity, and temperature is selected to be investigated at different time and position using the data obtained by DNSs. The self-similar evolution of the pdf in the phase space will be also discussed in this part. In the fourth part, a comprehensive self-similarity analysis for fluid and particle mean temperature fields in differential and integral forms is performed and the theoretical findings are validated with the numerical results. Finally, in the last part, a new theory for detecting the thermal caustics in turbulent non-isothermal flows laden with particles, is proposed. This theory can be used to determine the flow condition at which particle temperature gradient field has a finite-time singularity.