What large vacuum systems can learn from micro gas flows – and vice versa

Dr.-Ing. Christian Day
Karlsruhe Institute of Technology (KIT), Institute for Technical Physics,
76021, Karlsruhe, Germany

Abstract

The calculation of flows over a wide range of the Knudsen number has seen significant progress in the last decade, much triggered by R&D performed in support of microsystem design and by the increase of computational power. It is known that the deviation from the continuum hypothesis and thermodynamic equilibrium and the dominance of surface and wall effects which appear in microflows result in fluid mechanics which is largely different from the conventional understanding of flows.

However, there are macroscopic systems which work in similar conditions, namely vacuum systems. These systems can be operated to maintain a certain pressure by pumping an incoming process gas flow or be used to pump out a chamber volume; in any case the flow may cover all regimes from viscous to free molecular. There are industrial applications like lithography, semiconductor or coating processes which are mainly operated in the transitional flow regime. Modern methods of non-equilibrium flow simulation have been used for the design and predictive modeling of a number of vacuum pump types (turbomolecular, drag, scroll), but there are only a few cases up to now where the complete system design has been rigorously based on simulation tools. The design of the vacuum systems of the nuclear fusion project ITER is one of the few examples. However, it has been noted that within industry, it is still not yet sufficiently known, and the traditional approaches with all their limitations, sometimes physically unsound, are still used.

This talk will outline how a vacuum system design can be based on a toolbox of methods encompassing Test Particle Monte Carlo, collisional Monte Carlo (DSMC), kinetic equation, CFD and a network modeler. For code validation, an experimental R&D programme has been launched at Karlsruhe Institute of Technology (KIT) with the aim to parametrically investigate rarefied gas flows through (macroscopic) ducts at acceptable accuracy over a wide range of Kn. The toolbox as well as the experimental work holds equally well for gas microflows and this lecture aims to bridge the gap between the macro and micro community.