Abstract

Topographical textures or surface corrugations are often employed in the discipline of microfluidics to achieve objectives such as mixing, modulation of wetting and frictional properties, and separations. Outside microfluidics, such textures form the basis of dragreducing riblets engineered to turbulent flows and are natural features of fractured rocks carrying oil or water in geological formations.

Motivated by such applications, macroscopic characterization of creeping Newtonian flows establishing wetted contact with topographies is undertaken theoretically, using the effective slip length tensor as a metric for unconfined flows and the hydraulic permeability tensor as a metric for confined flows. Flows longitudinal as well as transverse to one-dimensional grooved [striped patterns are analyzed using spectral and asymptotic methods. Continuum scale fully resolved finite-element simulations are employed to assess the usefulness of asymptotic predictions. The main asymptotic approach used in this thesis treats the ratio of the characteristic size of the topographical pattern to the pattern pitch as a small parameter, the dimensionless amplitude.

First, for sinusoidally corrugated no-slip surfaces in shear flow, analytical models usable over a significantly wider amplitude range than those available from the literature are developed, taking advantages of symbolic computations, numerical-graphical convergence studies with Domb-Sykes plots and series-improvement techniques like Euler and Shanks transformation and Padé approximants.

Next, flows over corrugated surfaces with intrinsic slippage are studied. To understand the interplay between curvature and slippage, scaling laws are formulated by analyzing the singularity behaviour of transverse shear flows over perfectly slipping corrugations, a problem important in understanding the limits of superhydrophobic drag reduction. Based on these scaling laws, four different regimes in the interplay are delineated. The resultant effective-slip-length predictions for sinusoidally corrugated surfaces possess comparable simplicity but a wider amplitude-range and intrinsic-slip range of applicability than those available from literature. A computer-extended regular

perturbation theory is also developed, which allows exceptionally accurate predictions even at reasonably large values of the 'small (amplitude) parameter'.

Confined pressure-driven flows are studied in this thesis using a grid-free semi-analytical approach based on spectral analysis. This method has a faster (exponential) decay of errors compared to discretization-based methods such as finite-differences and finiteelements, and is also easily reducible to new and known analytical forms in various disparate limits. Further, the method brings out crucial physical characteristics of the flow that are inaccessible to asymptotic methods. For example, the permeability in longitudinal flow is shown to transition from faster-than-Poiseuille to slower-than-Poiseuille permeation as pattern pitch is reduced.

The final contribution of this thesis is a spectral-asymptotic approach to model confined flows over complex topographies specifiable by an arbitrary continuous function. Using a novel decomposition of the channel height effects into exponentially and algebraically decaying components, a simple surface-metrology-dependent relationship, which connects the eigenvalues of the effective permeability tensor, is obtained. Representative topographies assessed numerically include the infinitely-differentiable topography of a phase-modulated sinusoid with multiple local extrema and zero-crossings and the nondifferentiable triangular-wave topography. Corners in triangular patterns and cusps in scalloped patterns are not found to be an impediment to meaningful and numerically accurate asymptotic predictions, contradicting an earlier suggestion from the literature. Several distinct applications of the theory to the friction-reduction and shear-stability performance of the recently developed lubricant impregnated patterned surfaces and scalloped and trapezoidal drag-reduction riblets are discussed, with comparison to experimental data from the literature for the last application.