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Transition to turbulence in a soft-walled microchannel[1]

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It is well known that the transition from a laminar to a turbulent flow in a rigid tube takes place at a Reynolds number of about 2100, and in a rigid channel at a Reynolds number of about 1200. Experimental results are presented to show that the transition Reynolds number could be as low as low as 200 in micro-channels of height 100 microns with a soft wall, provided the elasticity modulus of the wall is sufficiently low. At the point of transition, motion is observed in the walls of the channel, indicating that the instability is caused by a dynamical coupling between the fluid and the wall dynamics, which is qualitatively different from that in rigid tubes/channels. Theoretical calculations show that the transition Reynolds number depends on a dimensionless parameter $\Sigma = (\rho G R^2/\mu^2)$, where, ρ and μ are the fluid density and viscosity, G is the elastic modulus of the wall material, R is the cross-stream length scale and V is the maximum velocity. A low Reynolds number analysis indicates that there could be a transition even at zero Reynolds number when the dimensionless parameter $(V\mu/GR)$ exceeds a critical value. The mechanism of destabilisation is the transfer of energy from the mean flow to the fluctuations due to the shear work done at the fluid-solid interface. Two different types of instabilities are identified at high Reynolds number using asymptotic analysis, the inviscid mode instability for which the critical Reynolds number sales as $\Sigma^{1/2}$, and the wall mode instability for which the critical Reynolds number scales as $\Sigma^{3/4}$. Numerical continuation is used to extend the results to the intermediate Reynolds number regime. The low Reynolds number analysis is found to be in quantitative agreement with experiments. However, the high Reynolds number analysis is in agreement only if the wall deformation and consequent flow modification due to the applied pressure gradient is incorporated in the analysis. The flow after transition has transport coefficients up to five orders of magnitude higher than that in laminar flows, and so the transition could be used to significantly enhance transport rates in microfluidic and biomedical applications.

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