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Dynamics of viscoelastic pipe flow at low Reynolds numbers in the maximum drag reduction limit. (English) Zbl 1419.76040

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Summary: Polymer additives can substantially reduce the drag of turbulent flows and the upper limit, the so-called state of 'maximum drag reduction' (MDR), is to a good approximation independent of the type of polymer and solvent used. Until recently, the consensus was that, in this limit, flows are in a marginal state where only a minimal level of turbulence activity persists. Observations in direct numerical simulations at low Reynolds numbers (Re) using minimal sized channels appeared to support this view and reported long 'hibernation' periods where turbulence is marginalized. In simulations of pipe flow at Re near transition we find that, indeed, with increasing Weissenberg number (Wi), turbulence expresses long periods of hibernation if the domain size is small. However, with increasing pipe length, the temporal hibernation continuously alters to spatio-temporal intermittency and here the flow consists of turbulent puffs surrounded by laminar flow. Moreover, upon an increase in Wi, the flow fully relaminarizes, in agreement with recent experiments. At even larger Wi, a different instability is encountered causing a drag increase towards MDR. Our findings hence link earlier minimal flow unit simulations with recent experiments and confirm that the addition of polymers initially suppresses Newtonian turbulence and leads to a reverse transition. The MDR state on the other hand results at these lowRe from a separate instability and the underlying dynamics corresponds to the recently proposed state of elasto-inertial turbulence.

MSC:

76A10 Viscoelastic fluids
76F06 Transition to turbulence
76F70 Control of turbulent flows

Keywords:

drag reduction; turbulent transition; viscoelasticity

Software:

Openpipeflow

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