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THE EFECT OF POLYMERS ON THE DYNAMICS OF TURBULENCE IN A DRAG REDUCED FLOW

ABSTRACT

An experimental investigation of a polymer drag reduced flow using state-of-the-art laser-Doppler anemometry in a refractive index-matched pipe flow facility is reported. The measured turbulent stresses deep in the viscous sublayer are analyzed using the tools of invariant theory. It is shown that with higher polymer concentration the anisotropy of the Reynolds stresses increases. This trend is consistent with the trends extracted from DNS data of non-Newtonian fluids yielding different amounts of drag reduction. The interaction between polymer and turbulence is studied by considering local stretching of the molecular structure of a polymer by small-scale turbulent motions in the region very close to the wall. The stretching process is assumed to re-structure turbulence at small scales by forcing these to satisfy local axisymmetry with invariance under rotation about the axis aligned with the main flow. It is shown analytically that kinematic constraints imposed by local axisymmetry force turbulence near the wall to tend towards the one-component state and when turbulence reaches this limiting state it must be entirely suppressed across the viscous sublayer. Based on this consideration it is suggested that turbulent drag reduction by high polymers resembles the reverse transition process from turbulent to laminar. Theoretical considerations based on the elastic behavior of a polymer and spatial intermittency of turbulence at small scales enabled quantitative estimates to be made for the relaxation time of a polymer and its concentration that ensure maximum drag reduction in turbulent pipe flows, and it is shown that predictions based on these are in very good agreement with available experimental data.

KEYWORDS

turbulence, transition, boundary layer, turbulent drag reduction, polymers, internal flows

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