Flexible fibers in turbulent channel flow

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We numerically investigate the dispersion of slender flexible fibers in turbulent channel flow. In particular, we examine fiber orientation and deformation at varying fiber inertia, aspect ratio and bending stiffness. We use a Euler-Lagrangian approach based on DNS of the flow, combined to a rod-chain pointwise representation of the fibers[1] and accounting for the inter-phase momentum exchange.[2] The simulations are performed exploiting a GPU-accelerated pseudo-spectral solver at shear Reynolds number Re=300, moderate mass fraction (3%) with fibers of aspect ratio r=50, 100, 200, dimensionless length L^+ = 18, 36, 72 (extending up to the inertial range of the turbulent flow) and Stokes number St= 0.1, 0.11, 11. For each combination of (r, L^+, St) values, different fiber rigidities are considered depending on the dimensionless Young modulus: E_Y^+= 0 (no stiffness) and 10^4 (moderate stiffness). Our results show that the fibers in the bulk of the flow orient with the local strain, aligning with the vorticity, as also observed in HIT,[3] and experience a lower tumbling rate, comparable to that of rigid fibers.[4] Near the walls, vorticity orients with the spanwise direction under the action of the mean shear, whereas flexible fibers align with the mean flow. This orthogonality determines a stronger contribution of the flow rotation to the tumbling rate. We classify the possible deformed shapes in a bi-variate probability space, suggesting that two main deformation patterns exist: "eyelash" bending and "compressive" buckling (the latter being suppressed with a finite, albeit moderate, bending stiffness). Flexible fibers in wall turbulence spend a short time in a bent state, before being stretched again by the flow: This time scales with the fiber rotation timescale and exhibits a gamma distribution.

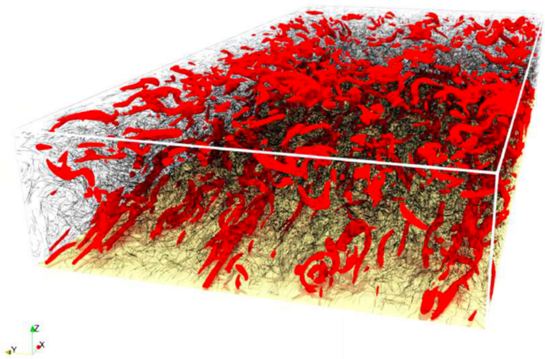

Fig. 1 Instantaneous visualization of the fiber-laden turbulent channel flow. flow. Flow structures are rendered as iso-surfaces of the 2nd invariant Q of the fluid velocity gradient tensor (Q = 0.02, corresponding to one tenth of the maximum value of Q obtained in the simulations); the diameter of the fibers is 3 times larger than the actual value for visualization purposes.

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