# Dissipation reduction in turbulent flows with polymer additives

Prasad Perlekar[1] Dhrubaditya Mitra[2,3] Rahul Pandit[1]

29 October 2006

[1] Indian Institute of Science, Bangalore, 560012 India.
[2] Laboratoire Casiopée, Observatoire de la Côte d'Azur, Nice France
[3] Queen Mary College, London, UK

*Abstract submitted to EE250*

The existence of drag reduction by polymer additives, well established for wall-bounded turbulent flows, is controversial in homogeneous, isotropic turbulence, compare for example Refs. [1] with Ref. [2]. To settle this controversy we carry out a high-resolution direct numerical simulation (DNS) of *decaying*, homogeneous, isotropic turbulence with polymer additives.

The governing equation are the Navier–Stokes equation coupled to the Finitely Extensible Nonlinear Elastic Peterlin (FENE-P) model [3] for polymers. We use a numerical method which preserves the symmetric and positive definite (SPD) nature of the polymer configuration matrix. This algorithm consists of sixth-order finite difference scheme for the polymer equation and spectral scheme for the Navier–Stokes equation.

We monitor the decay of turbulence from initial states in which the kinetic energy of the fluid is concentrated at small wave numbers; this energy then cascades to large wave numbers where it is dissipated by viscosity. Figure (1a) shows how $\epsilon$ first increases with time, reaches a peak, and then decreases; for $c = 0$ (fluid without any polymers) this peak occurs at $t = t_m$. The position of this peak changes mildly with $c$ but its height drops significantly as $c$ increases. As in [5] we use this phenomenon to define the percentage drag or dissipation reduction for decaying homogeneous, isotropic turbulence:

$$\mathrm{DR} \equiv \left( \frac{\epsilon^{f,m} - \epsilon^{p,m}}{\epsilon^{f,m}} \right) \times 100; \tag{1}$$

here (and henceforth) the superscripts $f$ and $p$ stand, respectively, for the fluid without and with polymers and the superscript $m$ indicates the time $t_m$.

Our work thus resolves the controversy about drag reduction in decaying homogeneous, isotropic turbulence and shows that Eq. (1) offers a natural definition of DR. We also find a nontrivial modification of the fluid kinetic-energy spectrum especially in the far-dissipation range [Fig. (1)] that can be explained

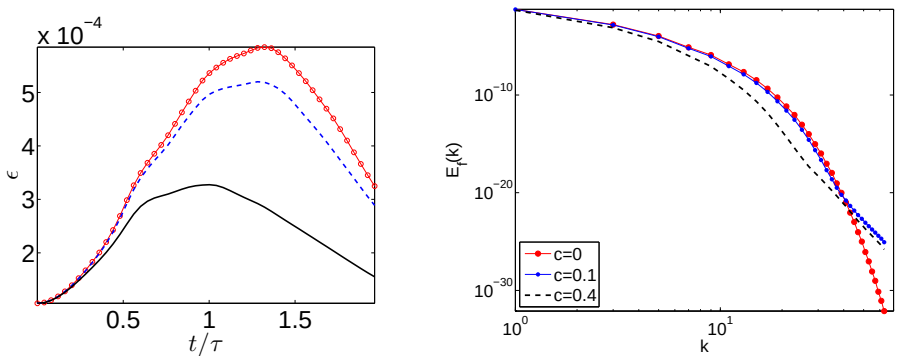


Figure 1: (a) Temporal evolution of the energy dissipation rate $\epsilon$ for concentrations $c = 0.1(--)$ and $c = 0.4$ (solid line), with $\tau \equiv \sqrt{2\mathcal{E}(t=0)/3\mathbb{L}^2}$; (b) Plots of the energy spectra $E_f(k)$ versus $k$ for $c = 0.1(--)$ and $c = 0.4$(solid line). Note the significant change in the far dissipation range.

in terms of a polymer-induced, scale-dependent viscosity. We further observe that on addition of polymers small-scale intermittency is suppressed, and vorticity filaments destroyed.

Further details are available in Ref. [3].

# References


[1] D. Bonn, Y. Couder, P. van Dam, and S. Douady, Phys. Rev. E **47**, R28 (1993).

[2] D. Bonn *et al.*, J. Phys. CM **17**, S1219 (2005).

[3] P. Perlekar, D. Mitra and R. Pandit, Phys. Rev. Lett, in press, nlin.CD/0609066.

[4] P. Virk, AIChE **21**, 625 (1975).

[5] C. Kalelkar, R. Govindarajan, and R. Pandit, Phys. Rev. E **72**, 017301 (2004).

[6] A. Peterlin, J. Polym. Sci., Polym. Lett. **4**, 287 (1966); H. Warner, Ind. Eng. Chem. Fundamentals **11**, 379 (1972); R. Armstrong, J. Chem. Phys. **60** 724 (1974); E. Hinch, Phys. Fluids **20**, S22 (1977).

[7] J. Hoyt and J. Taylor, Phys. Fluids **20**, S253 (1977).