Stretch and scission: estimations on polymer cleavage in small scale turbulent vortices during drag reduction

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Polymer additives have been found to efficiently reduce drag in turbulent pipe flows [1] and diminish the energy required for mass transfer through pipes. This is intrinsically accompanied by scission of the long, flexible polymer chains required for drag reduction (DR). Not only the mechanism of polymer DR is not fully understood, also the physics of polymer cleavage is still under discussion. Some studies claim polymers will be fully stretched in the shear of the boundary layer [2]. Others expect a partial stretching of the polymers in the local shear of turbulent flow vortices [3,4]. Both mechanisms require stretching of the polymer to be faster than its relaxation. We focus on the potential interaction of the polymers with turbulent vortice structures in the bulk since our experiments indicate DR to be dominated by volume processes rather than boundary layer effects [5]. Estimations of the involved length and time scales of polymer and turbulence and of the forces acting on the polymer chain are compared to our recent observations of polymer degradation in tubulent pipe flow [6,7]. Polymer stretching in turbulent vortices has to be expected, but scission is predicted for molecules of very high molecular mass only; much larger than observed in experiment where the fragments had molecular weights of 10^6 g/mol and less.

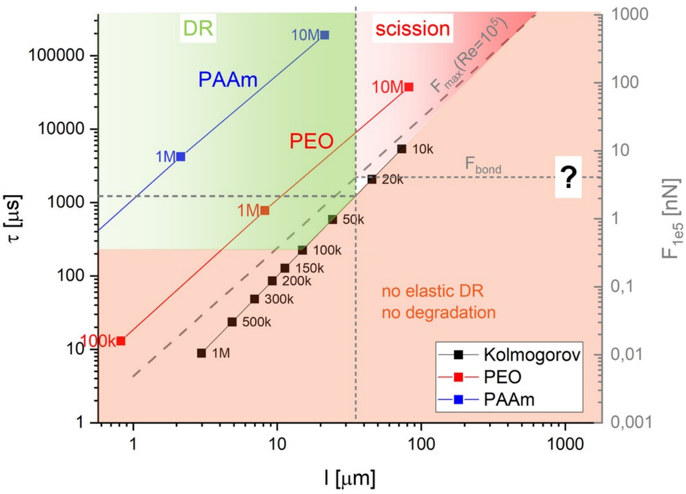

Figure: Time – size relation of turbulent structures in the Kolmogorov cascade (black solid line). Labels provide the minimum vortex size in dependence of the Reynolds number. Zimm time and maximum extensibility for two polymers (red and blue solid line, labels indicate the molecular weight). The broken line represents the maximum force acting on the polymer chain in dependence of the chain length for Re=10^5. Background colours in the graph display the parameter range where polymer scission (red) and drag reduction is expected (green and red).

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References

[1] Toms B.A. *Proceedings of the 1st International Congress on Rheology* **1948**, 135.

[2] Lumley J.L. *Annu. Rev. Fluid Mech.* **1969** 1 (1), 367

[3] Tabor M.; de Gennes P.G. *Europhysics Letters* **1986** 2(7):519

[4] Vanapalli S.A., et al. *PNAS* **2006** 103(45):16660

[5] Brandfellner L.; Bismarck A.; Müller H.W. *Physics of Fluids* **2025**, 37, 035175

[6] Müller H.W.; Brandfellner L.; Bismarck A. *Physics of Fluids*, **2023**, 35(2):023102.

[7] Brandfellner L.; Muratspahić, E.; Bismarck A.; Müller H.W. *JNNFM* **2024**, 325:105185