SPINODAL DECOMPOSITION IN THE INVERSE CASCADE OF TWO-DIMENSIONAL, BINARY-FLUID TURBULENCE

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Abstract We study spinodal decomposition in the inverse-cascade regime of two dimensional turbulence in symmetric, binary fluid mixtures. We show that turbulence leads to break up of domains whose size, in the inverse cascade regime, is proportional to the Hinze scale. Even more strikingly, we show that the inverse cascade of energy is blocked by the formation of domains.

INTRODUCTION

Studies of two dimensional ($2d$) flows or flows in thin films in turbulent regime are fundamental to our understanding of a variety of oceanographic and atmospheric flows. Turbulent flows in $2d$ are characterised by a transfer of energy from the forcing scales to larger length scales, and small vortices merge to form larger vortices as first predicted theoretically by Kraichnan [1]. In physical situations the transfer of energy to large scales is blocked by the presence of boundaries or air friction [2, 3, 4, 5, 6]. There is also a forward cascade of enstrophy (the mean square vorticity) from the forcing length scale to smaller length scales.

A symmetric, binary fluid mixture, undergoes spontaneous demixing below its critical temperature. Domains of the two pure phases keep on merging to form larger and larger domains until there is one interface separating the two pure phases [9, 11]. The growth rate of domains is governed by an interplay between the surface tension, the viscous, and the inertial forces. Depending upon the dominant balance between these forces, various growth laws for the domains have been predicted [10, 13, 16]. Experiments [15] in high-Schmidt-number mixtures ($Sc \equiv \nu/D$, ν is the viscosity and D is the diffusivity of the binary mixture) have shown that, in the presence of three-dimensional turbulence, domain growth is arrested. This arrest was theoretically explained by using a linear-stability analysis and by invoking an effective diffusivity [7]. Recent, high resolution simulations of turbulent symmetric binary mixtures in two [8] and three [14] dimensions have shown that the arrest phenomena is also present in binary mixtures for which $Sc \simeq 1$. The exact mechanism of the coarsening arrest is, however, different in different cases.

We study coarsening arrest by turbulence in a two-dimensional turbulence in the inverse-cascade regime. They showed that size of domains smaller than the forcing scale is controlled by the average shear across the domain. This has been studied earlier in Ref. [8]; but the authors of that study have concentrated on the forward-cascade region mentioned above.

RESULTS

We study coarsening arrest in the inverse cascade regime of two-dimensional turbulence by conducting direct numerical simulations (DNS) of the Navier-Stokes coupled to the Cahn-Hilliard equations. We keep the energy-injection rate fixed and vary the Weber number We (a dimensionless ratio of the inertial and surface tension forces). The pseudocolor plot of the order parameter field [Fig. 1] shows that if we increase We, large domains are replaced by small domains i.e., we have coarsening arrest. We show, in addition, that the coarsening arrest length is set by the Hinze length scale [12] which has been used in the context of break up of droplets in a turbulent flow.

CONCLUSIONS

We present a detailed study of spinodal decomposition in a symmetric binary fluid mixture in the inverse-cascade regime of two-dimensional turbulence. Our study shows that Hinze scale provides a natural estimator of domains whose average size is larger than the forcing scale. These domains form a natural boundaries which block the inverse energy cascade to large scales. We also investigate how the domain sizes depend on the mobility of the mixture.

References

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Figure 1. Pseudocolor plots of the order parameter field in the inverse-cascade regime in a two-dimensional turbulent binary-fluid mixture with increasing Weber number $We = 1.2 \cdot 10^{-2}$ (top left), $We = 5.9 \cdot 10^{-2}$ (top right), $We = 1.2 \cdot 10^{-1}$ (bottom left), and $We = 5.9 \cdot 10^{-1}$ (bottom right).

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