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Percolation transport in random flows with drift and time-dependence effects

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Abstract

This paper considers the influence of drift flow and time-dependence effects on the passive scalar behavior in the framework of the percolation approach. It is suggested to modify the renormalization condition of the small parameter of the percolation model in accordance with the additional external influences superimposed on the system. This approach makes it possible to consider simultaneously both parameters: the characteristic drift velocity U_d and the characteristic perturbation frequency ω. The effective diffusion coefficient $D_{eff} \propto \omega^{1/7}$ satisfactory describes the low-frequency region ω in which the long-range correlation effects play a significant role.

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1. Introduction

The analysis of correlation effects plays an important role in the description of turbulent transport. In spite of considerable progress attained in this field of research

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[1–5], the problem still awaits its complete solution. One of the important directions is obtaining scaling laws that characterize the turbulent diffusion of a passive scalar. Turbulent diffusion models differ significantly from one-dimensional transport models. Often several different transport types are simultaneously present in the turbulent diffusion [6–8]. A variety of forms requires not only special description methods, but also an analysis of general mechanisms for different turbulence types. One such mechanism is the percolation transport [9]. Its description is based on the idea of long-range correlations, borrowed from theory of phase transitions and critical phenomena [10,11]. These long-range correlations are responsible for the anomalous transport. It was suggested [12] that in two-dimensional cases we could explain the anomalous transport in terms of the percolation threshold. The percolation approach looks very attractive because it gives a simple and, at same time, universal model of behavior related to the strong correlation effects. The percolation approach, in fact, gives the possibility to effectively realize the scaling representation of correlation scale and to obtain the dependences of transport coefficients on the parameters characterizing common properties of a flow (velocity, spatial scale λ, "seed" diffusion D_0 etc.). Thus, in the framework of the percolation model the interesting results [13] were obtained that show the possibilities of the transition from the quasi-linear character of the dependence of the effective diffusion coefficient on the velocity scale

$$D_{eff} \approx \frac{V_0^2}{\omega} \approx \lambda^2 \omega \left(\frac{V_0}{\lambda\omega}\right)^2 \propto V_0^2, \tag{1}$$

to the regime with the non-conventional kind of dependences

$$D_{eff} \approx \lambda V_0 \left(\frac{\lambda\omega}{V_0}\right)^{3/10} \propto V_0^{7/10}. \tag{2}$$

Here V_0 is the characteristic velocity, λ is the characteristic size of strictures, and ω is the characteristic frequency of perturbations. The analysis of percolation transport effects is based on modified diffusive estimate $D_{eff} \approx (a^2/\tau_{COR})P_\infty$ and mean field arguments to describe the correlation length $a(\varepsilon_*)$ and the correlation time $\tau_{COR}(\varepsilon_*)$. Here, P_∞ is the percolation fraction of space (the fraction of space occupied by the percolation streamline) and ε_* is the small percolation parameter, which describes a closeness of the system to the percolation threshold [6,9–11]. An important aspect of the percolation approach is the method of obtaining the small parameter ε_* that characterizes the closeness of a system to a percolation threshold. Thus, the characteristic correlation length $a(\varepsilon_*)$ and the length of the percolation streamline $L(a)$ are expressed through this parameter

$$a = \frac{\lambda}{|\varepsilon_*|^{\nu}}, \quad L(a) \approx \lambda \left(\frac{a}{\lambda}\right)^{D_h}. \tag{3}$$

Here, $\nu = \frac{4}{3}$ and $D_h = 1 + 1/\nu$ are the percolation exponents, which are exactly calculated for the two-dimensional case [9–11], this allows one to obtain the