TURBULENT DIFFUSION OF INERTIAL PARTICLES IN THE FIELD OF MASS FORCES

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Based on Corrsin's hypothesis of independent averaging of the liquid particle trajectories and of the Euler correlations of velocity fluctuations we have analyzed the turbulent dissipation of an inertial particle impurity with regard to the averaged sliding of discrete and continuous phases.

The turbulent diffusion of a discrete impurity of inertial particles is encountered in numerous engineering applications, for example, in processes of chemical technology and energetics, and is also realized in natural phenomena such as atmospheric pollution as well as transfer of suspensions and microorganisms by sea flows. Owing to particle inertia and to the effect of mass forces caused by gravitational and electromagnetic fields, the rate of particle dissipation differs essentially from the rate of turbulent diffusion of a passive impurity. Predicting the turbulent diffusion of an inertialess impurity requires information on the Lagrange characteristics of the velocity fluctuations of isolated liquid particles. At present, the Lagrange autocorrelation function of velocity fluctuations is found by processing experimental data on dissipation of a passive impurity in a turbulent flow [2, 3] or through direct stochastic modeling of the velocity of liquid particles in a specified random field of Euler fluctuations related to the selected spatial point [4-6]. In practice, measurement of the Euler characteristics of a random field is realized much more easily than determination of the Lagrange correlations for tagged liquid particles. In this case, it is necessary to establish the relationship between the Lagrange and Euler fluctuation scales. We point out that there are two types of Euler correlations: first, that in the fixed (laboratory) coordinate system. Spatial and temporal scales of the fluctuations are related to one another based on Taylor's hypothesis of "frozen turbulence," which holds that the fluctuation characteristics of the random field have not changed appreciably over the time of displacement of the turbulent flow with an averaged velocity for a distance of the order of spatial macroscale. Through a point isolated in the laboratory system liquid particles continually pass, whose velocities are correlated much less than the velocity of an individual liquid particle on its own trajectory. Consequently, the Lagrange temporal scale of velocity fluctuations is larger than the Eulerian, referred to a fixed coordinate system [7]. In the second case, when the Euler correlations are determined in a coordinate system moving with the averaged flow velocity, the relationship between the values of the Lagrange and Euler temporal velocity fluctuations is not as evident as in the previous situation. We note Kraichnan's remark [8] that the approximation of "frozen turbulence" corresponds to an infinite Euler temporal scale found in the coordinate system with origin fixed at the carrier flow, whereas the Lagrange scale of fluctuations of the liquid particles is finite. Presently it is maintained in the literature that the Euler temporal macroscale related to the averaged flow velocity exceeds the Lagrange scale of turbulent velocity fluctuations [3-6, 9-12]. Physically, this circumstance is argued in the following way. The isolated liquid particle moves by the action of a great number of overlapping random structures forming the Euler fluctuation field. As a result of summing the assemblage of random effects on the liquid particle, its displacement may be modeled by a random process, statistically independent of the Euler field and having a Gaussian distribution. This hypothesis was advanced by Corrsin [1] and is often used for analyzing the turbulent diffusion of a scalar impurity and for establishing a correspondence between the Lagrange and Euler correlations [4, 9-13]. It should be noted that the Euler field of velocity fluctuations is characterized by spatial and temporal macroscales, with the ratio of the spatial scale to the product of the temporal scale and the characteristic fluctuating velocity governed by the flow type rather than being a universal constant [11, 12], which determines the dependence of the relationship between the Lagrange and Euler temporal macroscales on the way in which the turbulent flow is realized.

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The intensity of the turbulent motion of particles is largely dependent on the relation between the Euler and Lagrange temporal macroscales. The random trajectories of finely dispersed particles are close to those of the liquid particles, and the fluctuation characteristics of the impurity are specified by the Lagrange scales. For larger particles whose dynamic relaxation time exceeds the Lagrange temporal scale, the fluctuation intensity is determined by the Euler scales [14]. In the averaged sliding of the phases, there is a constant renewal of liquid moles on the particle trajectory, causing a decrease in the characteristic decay time of the correlation of the gas velocity fluctuations on the trajectory in comparison with the correlations of the gas proper [15, 16]. The effect of "intersection of trajectories" on the intensity of turbulent dissipation of the impurity was studied experimentally in [17, 18]. A theoretical interpretation of this phenomenon invokes Corrsin's hypothesis [1] of independent averaging for the trajectories of discrete particles and the Euler correlations of the velocity field of a liquid phase [19-22].

The current study has calculated, using a unified approach, both the relationships between the Lagrange and Euler correlations for velocity fluctuations of the carrier phase and the effect of the particle inertia and of the averaged sliding velocity of the phases on turbulent dissipation of the dispersed impurity. Calculated results are compared with experimental data [17, 18].

1. We consider the Lagrange correlation for velocity fluctuations of the liquid phase

$$\langle u_{fi}(t)u_{fj}(t_1)\rangle = \langle u_i(\mathbf{R}_f(t),\ t)u_j(\mathbf{R}_f(t_1),\ t_1)\rangle = \int d\mathbf{x}\int d\mathbf{x}_1 \langle u_i(\mathbf{x},\ t)u_j(\mathbf{x}_1,\ t)\,\delta(\mathbf{x}-\mathbf{R}_f(t))\,\delta(\mathbf{x}_1-\mathbf{R}_f(t_1))\rangle \quad (1)$$

In Eq. (8), we convert to coordinate system moving together with the flow

$$\mathbf{x}' = \mathbf{x} - \mathbf{U}t,\quad \mathbf{x}_1' = \mathbf{x}_1 - \mathbf{U}t_1,\quad \mathbf{R}_f(t) = \mathbf{U}t + \int_0^t ds\mathbf{u}_f(s).$$

We define the Euler correlation for velocity fluctuations of the gas in a coordinate system with origin fixed at the averaged flow:

$$\langle u_i(\mathbf{x}'+\mathbf{U}t,\ t)u_j(\mathbf{x}_1'+\mathbf{U}t_1,\ t_1)\rangle = \langle R_{ij}^E(\mathbf{X},\ \mathbf{Y},\ s,\ t^0)\rangle,$$

$$\mathbf{X} = (\mathbf{x}_1'+\mathbf{x}')/2,\quad \mathbf{Y} = \mathbf{x}'-\mathbf{x}_1',\quad s = t-t_1,\quad t^0 = (t+t_1)/2.$$

As a result, we write an expression for the Lagrange correlation of velocity fluctuations of the liquid particles

$$\langle u_{fi}(t)u_{fj}(t_1)\rangle = \int d\mathbf{X}\int d\mathbf{Y}\Big\langle R_{ij}^E(\mathbf{X},\ \mathbf{Y},\ s,\ t^0)\times\delta\Big\{\mathbf{X}-\frac{1}{2}\Big[\int_0^t ds\mathbf{u}_f(s)+\int_0^{t_1} ds\mathbf{u}_f(s)\Big]\Big\}\,\delta\Big(\mathbf{Y}-\int_{t_1}^t \mathbf{u}_f(s)ds\Big)\Big\rangle. \quad (2)$$

Let L and T denote the characteristic spatial scales of variation of the function R^E_{ij} with respect to the relative variables **Y** and s. When the inequalities

$$L\partial\ln R_{ij}^E(\mathbf{X},\ \mathbf{Y},\ s,\ t^0)/\partial X_k \ll 1,\quad T\partial\ln R_{ij}^E(\mathbf{X},\ \mathbf{Y},\ s,\ t^0)/\partial t^0 \ll 1$$

are fulfilled the variation in the function R^E_{ij} with respect to the variables **X** and t^0 in expression (2) may be neglected. Expression (8) takes the form

$$\langle u_{fi}(t)u_{fj}(t+s)\rangle = \langle u_iu_j\rangle R_{ij}^L(s) = \int d\mathbf{Y}\ \langle R_{ij}^E(\mathbf{Y},\ s)G_f(\mathbf{Y},\ s)\rangle, \quad (3)$$

$$G_f(\mathbf{Y},\ s) = \delta\Big(\mathbf{Y}-\int_0^s ds'\mathbf{u}_f(s')\Big). \quad (4)$$

Here, $G_f(\mathbf{Y}, s)$ is the probability density of displacement of the liquid particle by the distance **Y** over the time s. Going to the Fourier representation of the function R^E_{ij} with respect to the variable **Y**, we write

$$\langle u_iu_j\rangle R_{ij}^L(s) = \int d\mathbf{k}\Big\langle \Phi_{ij}^E(\mathbf{k},\ s)\exp\Big(-ik_n\int_0^s ds'u_{fn}(s')\Big)\Big\rangle, \quad (5)$$

where $\Phi^E_{ij}(\mathbf{k}, s)$ is the Fourier transform of the correlation function $R^E_{ij}(\mathbf{Y}, s)$ with respect to the variable $\mathbf{Y}$. Using Corrsin's hypothesis [1] under the assumption that the character of the velocity fluctuations of the liquid particles is Gaussian, we obtain expression (5) in the form

$$\langle u_i u_j \rangle R^L_{ij}(s) = \int d\mathbf{k} \langle \Phi^E_{ij}(\mathbf{k}, s) \rangle \exp\left(-\frac{1}{2} k_n k_m Y^2_{nm}\right), \tag{6}$$

where Y^2_{nm} is the square of the displacement of the liquid particles:

$$Y^2_{nm} = \langle u_n u_m \rangle 2 \int_0^s ds' (s - s') R^L_{nm}(s'). \tag{7}$$

From the expression for the Lagrange autocorrelation function for velocity fluctuations of the liquid particles R^L_{ij} we find the characteristic temporal Lagrange scale of velocity fluctuations

$$T^L_{nm} = \int_0^\infty ds R^L_{nm}(s). \tag{8}$$

To simplify computations, we compute the square of the displacement of the liquid particles over the Lagrange scale time ($s = T^L_{nm}$ in Eq. (7)). Moreover, in Eq. (7) we approximate the function R^L_{nm} in the form $R^L_{nm} = \Delta(T^L_{nm} - s)$ ($\Delta(x)$ is the Heaviside step function). As a result we arrive at

$$Y^2_{nm} = \langle u_n u_m \rangle (T^L_{nm})^2. \tag{9}$$

Equations (6)-(9) permit us to obtain in closed form the relationship between the Lagrange and Euler characteristics of the flow as a function of the type of Euler field of the gas velocity fluctuations in a coordinate system with origin fixed at the flow.

The expression for the correlation of velocity fluctuations of the liquid particles in the laboratory coordinate system follows from Eqs. (3), (4), and (6):

$$\langle u_i u_j \rangle R^U_{ij}(s) = \int d\mathbf{Y} \left\langle R^E_{ij}(\mathbf{Y}, s)\, \delta\left(\mathbf{Y} - \mathbf{U}s - \int_0^s ds' \mathbf{u}_f(s')\right)\right\rangle = \int d\mathbf{k} \langle \Phi^E_{ij}(\mathbf{k}, s) \rangle \exp\left(-ik_n U_n s - \frac{1}{2} k_n k_m Y^2_{nm}\right). \tag{10}$$

The temporal scale of velocity fluctuations in the laboratory reference system is

$$T^U_{ij} = \int_0^\infty ds R^U_{ij}(s). \tag{11}$$

As an example of utilizing the relations obtained we consider the case of homogeneous turbulence. In this situation, we approximate the spectral function of fluctuations in the moving reference system in the form [12, 22]

$$\langle \Phi^E_{ij}(\mathbf{k}, s) \rangle = 16 (2\pi)^{-3/2} k_0^{-5} k^2 (\delta_{ij} - k_i k_j / k^2) \langle u_i u_j \rangle \times \exp[-2(k/k_0)^2 - \omega_0^2 s^2/2], \quad k^2 = k_i k_i, \tag{12}$$

where the integral spatial and temporal scales are equal, respectively, to

$$L = (2\pi)^{1/2}/k_0, \quad T = (\pi/2)^{1/2}/\omega_0.$$

Having substituted expression (12) into Eqs. (6)-(11) we find a relation between the temporal scales of velocity fluctuations of the liquid phase:

$$T^L/T = \beta = (1 + \pi/2\gamma^2\beta^2)^{-3/2}, \quad \gamma = \frac{uT}{L}, \tag{13}$$

$$T^L/T^U = (1 + \gamma^2\beta^2/\xi^2)^{1/2}, \quad \xi = u/U, \tag{14}$$

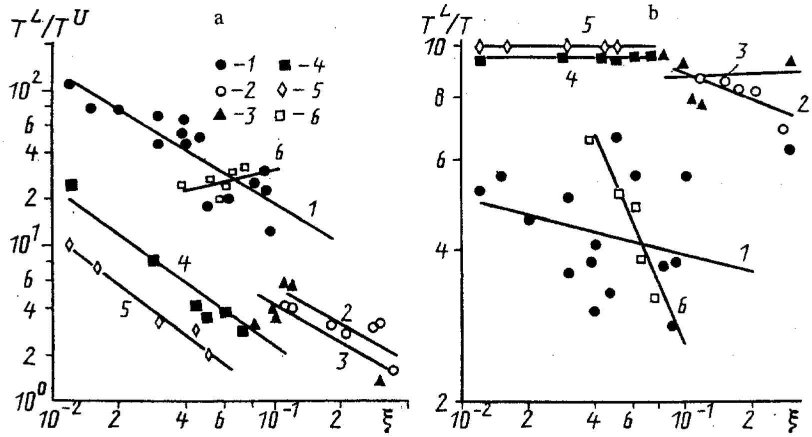


Fig. 1. Influence of the level of turbulent velocity fluctuations on the ratio of temporal scales measured in the laboratory coordinate system (a), and dependence of the ratio between the Lagrange and Euler temporal scales (b) on the level of turbulent fluctuations; dots denote experimental data, 1-5) [2], 6) [3]: 1) wake behind cylinder; 2) mixing zone of jet; 3) ground layer; 4) tube; 5) jet core; 6) turbulence behind lattice. $T^L/T \cdot 10^{-1}$.

where $u = \langle u_i u_i \rangle^{1/2}$, and ξ is the level of turbulent fluctuations of the gas velocity. The temporal scale in the laboratory system T^u is found for fluctuations of the velocity parallel to the averaged flow velocity. Relations (13) and (14) show that, from measurement data for the temporal scales in the laboratory system, we can establish the relationship between the Euler and Lagrange temporal scales in a coordinate system moving together with the flow. Here, the value of the parameter γ depends on the type of turbulent flow [12].

Figure 1 gives calculated results for the ratio between the Lagrange and Euler temporal scales (in a coordinate system with origin fixed at the flow) based on the data of laboratory measurements [2]. The figure also presents calculated results for the ratio of the temporal scales in the laboratory coordinate system based on experimental values of the ratio between the Lagrange and Euler scales in a coordinate system of the flow [3]. It is evident that, as distinct from the results of [2, 14], the ratio T^L/T is smaller than unity for all types of turbulent flows presented.

2. The Lagrange correlation of velocity fluctuations of a particle is of the form

$$\langle v_{pi}(t) v_{pj}(t_1) \rangle = \frac{\langle u_i u_j \rangle}{\tau} \int_0^t dt' \exp\left(-\frac{t-t'}{\tau}\right) \times \int_0^{t_1} dt_1' \exp\left(-\frac{t_1-t_1'}{\tau}\right) Q_{ij}(t', t_1'). \quad (15)$$

The function Q_{ij} is the correlation of velocity fluctuations of the liquid phase computed on the particle trajectory:

$$\langle u_i u_j \rangle Q_{ij}(t, t_1) = \int d\mathbf{x} \int d\mathbf{x}_1 \langle u_i(\mathbf{x}, t) u_j(\mathbf{x}_1, t_1) \times \times \delta(\mathbf{x} - \mathbf{R}_p(t)) \delta(\mathbf{x}_1 - \mathbf{R}_p(t_1)) \rangle .$$

Converting to a coordinate system moving with the carrier flow and restricting ourselves to the case of homogeneous and statistically stationary turbulence, we write an expression for the correlation of velocity fluctuations of the gas on the trajectory of a dispersed particle

$$\langle u_i u_j \rangle Q_{ij}(s) = \int d\mathbf{Y} \langle R_{ij}^E(\mathbf{Y}, s) G_p(\mathbf{Y}, s) \rangle . \quad (16)$$

The function $\langle G_p(\mathbf{Y}, s) \rangle$ represents the probability density of displacement of a discrete particle by the distance $\mathbf{Y}$ over the time s. In accordance with the results of [23], the probability density for the particle displacement in the space $\langle C_p(\mathbf{Y}, s) \rangle$ is connected with a more general probability density for the displacement $\langle C_p(\mathbf{Y}, s; v) \rangle$ that describes the particle displacement by the distance $\mathbf{Y}$ over the time s on the condition that the particle velocity at the initial instant of time is $\mathbf{v}$. The function $\langle G_p(\mathbf{Y}, s, \mathbf{v}) \rangle$ accounts for the inertia of the dispersed impurity and is written as

$$\langle G_p(\mathbf{Y}, s; \mathbf{v})\rangle = \left\langle \delta\left\{\mathbf{Y} - \mathbf{W}s - \mathbf{v}\tau\left[1 - \exp\left(-\frac{s}{\tau}\right)\right] - \int_0^s ds'\left[1 - \exp\left(-\frac{s'}{\tau}\right)\right]\mathbf{u}(\mathbf{R}_p(s'), s')\right\}\right\rangle. \tag{17}$$

Taking into account the Gaussian character of velocity fluctuations of the particles and the relation between the probability densities of displacement

$$\langle G_p(\mathbf{Y}, s)\rangle = \int d\mathbf{v}\varphi_p(\mathbf{v})\langle G_p(\mathbf{Y}, s; \mathbf{v})\rangle,$$

we write an expression for the correlation of velocity fluctuations of the gas on the particle trajectory

$$\langle u_i u_j\rangle Q_{ij}(s) = \int d\mathbf{k}\langle \Phi_{ij}^E(\mathbf{k}, s)\rangle \exp\left(-ik_n W_n s - \frac{1}{2}k_n k_m \Lambda_{nm}^2\right), \tag{18}$$

where Λ^2_{nm} is the square of the displacement of a discrete particle:

$$\Lambda_{nm}^2 = \langle v_n v_m\rangle \tau^2\left[1 - \exp\left(-\frac{s}{\tau}\right)\right]^2 + y_{nm}^2, \tag{19}$$

$$y_{nm}^2 = \langle u_n u_m\rangle\left\{2\int_0^s ds'(s - s')Q_{nm}(s') - \tau\int_0^s ds'\left[1 - \exp\left(-\frac{s - s'}{\tau}\right)\right]\times\right.$$
$$\left.\times\left[2 - \exp\left(-\frac{s'}{\tau}\right) + \exp\left(-\frac{s}{\tau}\right)\right]Q_{nm}(s')\right\}. \tag{20}$$

The temporal macroscale of turbulent fluctuations of the gas velocity on the particle trajectory is

$$\Theta_{nm} = \int_0^\infty ds Q_{nm}(s). \tag{21}$$

We compute the square of the displacement of a discrete particle in Eq. (18) at $s = \theta_{nm}$, prescribing the correlation $Q_{nm} = \Delta(\theta_{nm} - s)$. As a result, for the quantity Λ^2_{nm} we find

$$\Lambda_{nm}^2 = \langle v_n v_m\rangle\tau^2\left[1 - \exp\left(-\frac{\Theta_{nm}}{\tau}\right)\right]^2 + \langle u_n u_m\rangle\left\{\Theta_{nm}^2 - \tau^2\left[2\frac{\Theta_{nm}}{\tau}\times\right.\right.$$
$$\left.\left.\times\left(1 + \exp\left(-\frac{\Theta_{nm}}{\tau}\right)\right) - \left(3 + \exp\left(-\frac{\Theta_{nm}}{\tau}\right)\right)\left(1 - \exp\left(-\frac{\Theta_{nm}}{\tau}\right)\right)\right]\right\}. \tag{22}$$

For low-inertia particles ($\tau \to 0$), as is seen from Eq. (22), $\Lambda^2_{nm} = Y^2_{nm}$. The square of the particle displacement for the inertial impurity $\tau >> T$ decreases: $\Lambda^2_{nm} \sim \langle u_n u_m\rangle T/\tau T^2$.

Expressions (15), (18)-(22) enable us to determine in closed form the characteristics of the dispersed phase from the autocorrelation function of velocity fluctuations of a continuous medium, specified in the coordinate system of the flow.

3. To compare the calculated results for turbulent diffusion of particles subjected to mass forces with experimental data [17, 18], we calculate the fluctuation characteristics of the particles for the case of homogeneous isotropic turbulence generated behind the lattice in a wind channel. The correlation function of velocity fluctuations of the gas is given in the form (12). The velocity vector of phase sliding is $W_n = \delta_{1n}W$.

The correlations of velocity fluctuations of the gas on the particle trajectory in directions parallel and perpendicular to the sliding velocity of the phases are of the form

$$Q_{11}(s) = \mu_1^{-1}\mu_2^{-4}\exp\left[-\frac{\omega_0^2 s^2}{2}\left(1 + \frac{W^2 k_0^2}{4\omega_0^2\mu_1^2}\right)\right],$$
$$Q_{22}(s) = \frac{Q_{11}(s)}{2}\left[1 + \frac{\mu_2^2}{\mu_1^2}\left(1 - \frac{W^2 s^2 k_0^2}{4\mu_1^2}\right)\right], \quad \mu_i^2 = 1 + \Lambda_{ii}^2 k_0^2/4. \tag{23}$$

It follows from Eqs. (23) that a rise in the sliding velocity of the phases causes an intense decay of the correlations for velocity fluctuations of the gas on the particle trajectory.

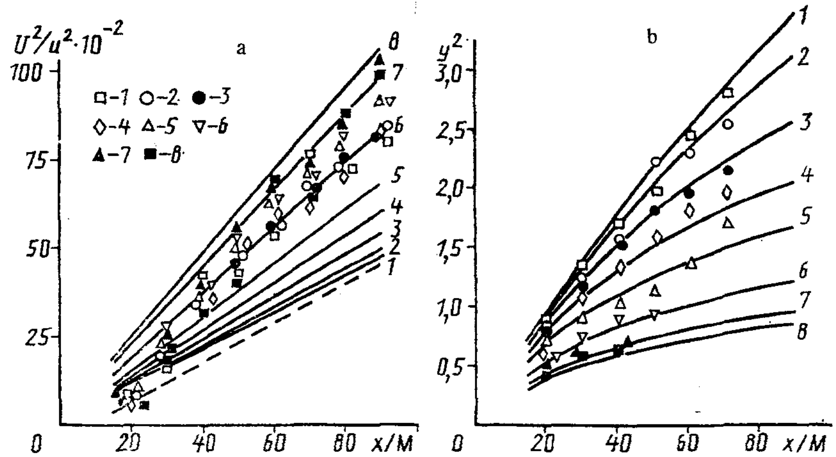
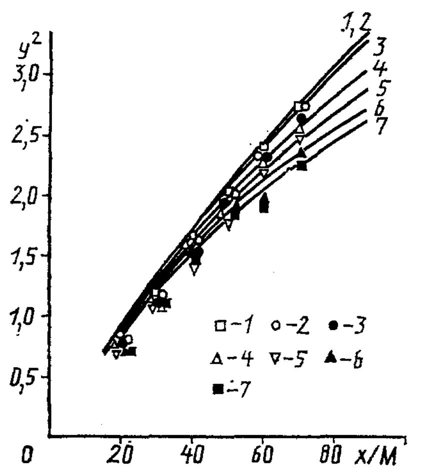


Fig. 2. Variation in the turbulent energy of particles (d_p = 57 μm) along the length of a wind channel at various sliding velocities of the phases (dots show experimental data [18], dash line shows fluctuating energy of a carrying gas, and solid lines show intensity of velocity fluctuations of particles) (a) and variation in the square of the turbulent displacement of particles (d_p = 57 μm) along the length of a wind channel (dots show experimental data [18] and curves calculation) (b): 1) W = 0; 2) 13.5 cm/sec; 3) 25.8; 4) 39.7; 5) 54.5; 6) 81.5; 7) 1.08; 8) 121.6. y, cm.



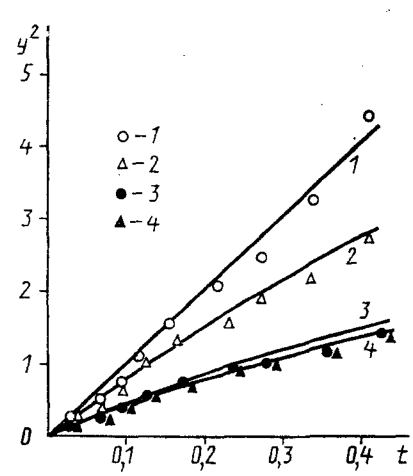


Fig. 3　　　　　　　　　　　　Fig. 4

Fig. 3. Variation in the square of the turbulent displacement of particles (d_p = 57 μm) along the length of a wind channel (dots show experimental data [18], and curves calculation): 1) W = 0, 2) 2.73 cm/sec, 3) 5.84, 4) 13.31, 5) 17.06, 6) 20.91, 7) 23.65.

Fig. 4. Effect of the rate of gravitational deposition of particles on the intensity of turbulent dissipation of impurity (dots show experimental data [17], and curves calculation): 1) $\tau = 1.7 \cdot 10^{-3}$ sec, 2) $20 \cdot 10^{-3}$, 3) $45 \cdot 10^{-3}$, 4) $49 \cdot 10^{-3}$. t, sec.

The temporal macroscales of velocity fluctuations of the gas on the trajectory and the turbulent diffusion coefficients are

$$\Theta_{11} = T\mu_1^{-1}\mu_2^{-4}(1 + W^2T^2/L^2)^{-1/2},$$

$$\Theta_{22} = \frac{\Theta_{11}}{2}\left\{1 + \frac{\mu_2^2}{\mu_1^2}\left[1 - \frac{W^2T^2/L^2}{\mu_1^2(1 + W^2T^2/L^2)}\right]\right\}, \quad D_{ii}^p = \Theta_{ii}\langle u_i^2\rangle . \tag{24}$$

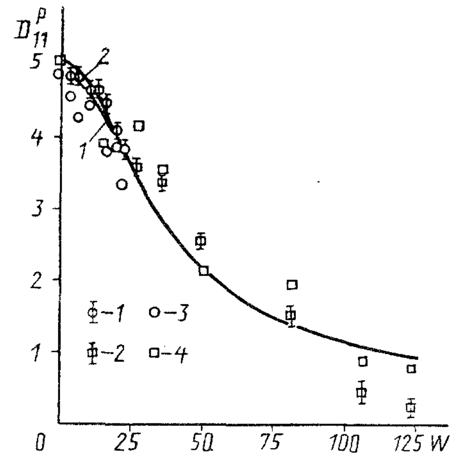


Fig. 5

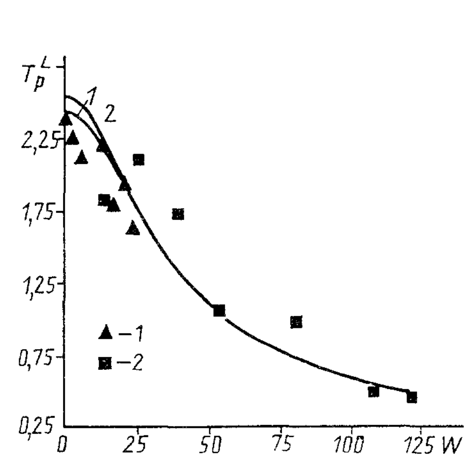


Fig. 6

Fig. 5. Turbulent diffusion coefficient of particles vs sliding velocity of phases (dots show experimental data [18], 1 and 3, d_p = 5 μm; 2 and 4, 57 μm; 1 and 2 are obtained from measurements of impurity dissipation; 3 and 4 from experimental values of the correlations for velocity fluctuations of particles in the laboratory reference system; curves show calculated results. D^p_{11}, cm^2/sec; W, cm/sec.

Fig. 6. Integral temporal scale of velocity fluctuations of particles T^U_p, msec, in the laboratory system vs sliding velocity (dots show experimental data [18], and curves calculation): 1) d_p = 5 μm, 2) 57.

The intensity of pulsatory motion of the particles in the direction of the averaged sliding velocity is calculated from the equation

$$\langle v_1^2 \rangle = \frac{T}{\tau}\,\frac{\langle u_1^2 \rangle}{\mu_1\mu_2^4}\left(1+\frac{W^2T^2}{L^2}\right)^{-1/2}\exp(A^2)\,\mathrm{erfc}\,(A),$$

$$A = \frac{T}{\sqrt{\pi}\,\tau}\left(1+\frac{W^2T^2}{L^2}\right)^{-1/2}.$$

The integral scales k_0 and $\omega_0(L, T)$ in Eq. (12) are determined from experimental values of the decay time for the autocorrelation function of velocity fluctuations of the gas in the laboratory coordinate system T^U from Eqs. (13) and (14). The value of $\beta = T^L/T$ is chosen from experimental data [3], depending on the turbulence level ξ.

The temporal macroscales for the Lagrange correlation of velocity fluctuations of the particles T^L_p and for the correlation of velocity fluctuations of the impurity in the laboratory reference system are predicted as

$$T_p^L = \langle v_1^2 \rangle / D_{11}^p, \quad T_p^U = T_p^L (1+\gamma^2\beta^2/\xi^2)^{-1/2}.$$

Figure 2 illustrates the effect of the sliding velocity of the phases on the variation in the fluctuation energy of the dispersed impurity (d_p = 57 μm) and on the intensity of turbulent dissipation of the impurity in flow behind a turbulizing lattice. The averaged sliding was caused by the electric field acting on the impurity particles and directed normal to the flow velocity [18]. Clearly, with increasing velocity of sliding, an intense degeneracy of turbulence of the dispersed phase is observed. Due to the effect of "intersection of trajectories" the turbulent diffusion coefficient for the particles decreases, thus reducing the diffusional dissipation of the impurity in the field of mass forces. It should be noted that, for small particles (d_p = 5 μm [18]), the effect of the relative velocity of the particles on the degree of turbulence degeneracy for the particles is insignificant. However, a rise in the sliding velocity results in a decrease in the turbulent dissipation for the low-inertia impurity as well (Fig. 3).

Figure 4 presents simultaneous effects of the particle inertia and of the rate of gravitational deposition, directed along the averaged flow, on the turbulent mixing of the particles in the wind channel in relation to the time.

Figure 5 shows a comparison of calculated results for the turbulent diffusion coefficient of the particles to experimental data [18]. Evidently, for large particles with intensity of pulsatory motion determined by the Euler temporal macroscale, the turbulent diffusion coefficient is somewhat larger than for small particles. This conclusion is consistent with the results of [5, 14, 19, 22]. As the sliding velocity rises, the influence of inertia on the turbulent diffusion coefficient diminishes. Figure 6 depicts the influence of the sliding velocity of the phases on the characteristic temporal scale of velocity fluctuations of the impurity in the laboratory reference system. It also follows from the figure that, with increasing inertia of the particles, one can anticipate a growth of the temporal scales of velocity fluctuations for large particles as compared with a fine impurity.

NOTATION

$u_i(x, t)$, velocity fluctuation of the gas; $u_{fi}(t)$, Lagrange velocity of the liquid particle; $R_{fi}(t)$, coordinate of the liquid particle; **U**, averaged flow velocity; $R^L_{ij}(s)$, Lagrange correlation of velocity fluctuations of the liquid particles; $\langle R^E_{ij} \rangle$, Euler correlation of velocity fluctuations of the gas in a coordinate system with origin fixed at the flow; $\delta(\mathbf{x})$, Dirac delta function; $\varphi_p(\mathbf{v})$, probability density of the particle distribution in velocities; δ_{ij}, Kronecker symbol; D^P_{ii}, turbulent diffusion coefficient of the particles; x, coordinate along the flow axis; M, mesh size of the turbulizing lattice; d_p, diameter of the impurity particles; τ, time of dynamic relaxation of the particles; $\mathrm{erfc}(x) = 1 - \mathrm{erf}(x)$;

$$erf(x) = 2/\sqrt{\Pi} \int_0^x dt \exp(-t^2),$$

probability integral; Y^2, square of the particle displacement in the wind channel; W, relative velocity of the phases.

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