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INTERACTION OF LIGHT WITH A TURBULENT LIQUID

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A paper [1] recently published in a scientific journal summed up a recently conducted set of studies [2, 4] on the optics of heterogeneous media. A number of fundamental statements of these studies require examination.

§ 1. Turbulent pressure pulsations, reducing to, by means of density pulsations, fluctuations of the refractive index r, according to [1-4], are the basic factors resulting in scattering of light by a turbulent flow of a transparent liquid not undergoing external heat exchange.

These authors [1-4] were apparently not aware of the fact that the approach they adopted to the analysis of the phenomenon had already been used by other researchers and had been criticized in terms of the lack of theoretical correspondence to the actual conditions of a turbulent atmosphere. We may suggest that an analysis of the previous [5] data may have convinced these authors of the inapplicability of this approach for the case of turbulent flow of a dropping liquid they had considered.

§2. It was assumed [1-4] that in a liquid, "in particular, isothermal conditions may occur as light passes into the ocean and that turbulence will manifest itself in terms of the effect of pressure pulsations, as if the latter were low" [1]. Unfortunately, no grounds were given [1-4] for this disputable thesis regarding the substantial role of compressibility as light interacts with a liquid.

Results are given below of estimates of the degree of isothermicity in a turbulent liquid flow, such that the effective compressibility associated with pressure pulsations predominate over the effect of temperature pulsations. The dependence [1-4]

$$P' \approx \langle \rho \rangle \langle u \rangle u', \tag{2.1}$$

where $\langle \rho \rangle$ and $\langle u \rangle$ are the mean densities and velocities and P' and u' are pressure and velocity* pulsations, was the basis of the estimates.

It is assumed [6] that u' is 4% of the mean liquid velocity in the tube.

Results of the estimate show that it is necessary for the flow to become isothermal to within 10^{-5}° in order to ensure that pressure pulsations will predominate in the characteristic case examined by these

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* Apparently the presence of only the component u' in the dependence was due to the fact that the pulsating velocity components in a near-axial region of the turbulent flow in a tube are equal; P' and u' denote the root-mean-square values of the corresponding pulsations.

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experiments [1-4] (flow of water with temperature 20°C and velocity 1 m/sec). Isothermicity to within 10^{-6}°C was required in experiments using ethyl alcohol and Freon-113 (temperature 20°C, velocity 0.4 m/sec).

It is simultaneously necessary to take into account the highly important circumstance that the standard deviation of the velocity pulsation corresponds to eddies of comparatively great scale, and that only turbulent eddies of least scale may participate in light scattering; since the amplitude of the velocity pulsations substantially falls with decreasing turbulence scale [6, 7], we may conclude that as a result the isothermicity conditions must be even more stringent by a factor of 10-20.

The experimental tube was thermostatically controlled in these experiments to within 10^{-2}°C [1], and isothermicity to within 10^{-3}°C was ensured in only one experiment, the temperature here being controlled in the flow itself in terms of displacement of the bands* [3]. Consequently, it is no longer necessary to speak of insuring comparability [1-4] between theory and experiment.

The dissipation process occurring in a turbulent flow is nonuniform with respect to time and space and imposes theoretical constraints against achieving isothermicity of the required order. One conclusion [5] as to the theoretical inadequacy of this approach for analyzing optical phenomena in a turbulent atmosphere is no less justified for the case of a turbulent liquid.

§ 3. The turbulence intensity components are roughly equal [6] in the near-axial region of flow in a tube (all the experiments [1-4] refer to this region). This fact allows us to approximately describe the relation between the standard deviation of the static pressure pulsations and velocity by the well-known dependence [5-7]

$$P' \approx \rho u'^2. \tag{3.1}$$

Unfortunately, no justification was given in [1-4] for Eq. (2.1), which overstates P' in comparison with Eq. (3.1) by nearly a factor of 100.

§ 4. Substantial light scattering on flow inhomogeneities in the direction of the normal to the primary radiation has been determined [1-4]. Similar light scattering in the lateral direction occurs in the presence of scale irregularities noticeably less than the wave length of the incoming light [8]. Consequently, linear scale irregularities noticeably less than 0.5 μ occurred in the liquid flow in these experiments [1-4]. It can be uniquely proved that an admixture of foreign particles play the role of similar inhomogeneities in these experiments [1-4]. For this purpose we may refer to experimental studies of the structure of a turbulent water flow using a hydrodynamical microscope [9, 10].

According to these studies, the linear scale of the smallest eddies, under conditions practically coinciding with the experimental conditions [1-4], amounts to at least several hundred microns. Since the scale of the tagged particles introduced into the flow must be many times less, these dimensions are of theoretical importance for the method [9] as a whole. That is, the minimal scale of the eddies presented above allows us to use tagged particles measuring 10-30 μ in diameter.

Thus the scattering determined in these experiments [1-4] cannot be related to purely turbulent flow inhomogeneities. It was due to the presence of an admixture in the flow and turbulence played the role only of a mixing factor. On the whole, however, reliable data on the interaction of light with a similar turbulent liquid flow can be found in [11], which was a comprehensive and carefully conducted (both from the point of view of techniques and from the point of view of the interpretation of the experimental results) study of optical phenomena statistically reproduced in [1-4] with lesser clarity.

These drawbacks were due not only to a lack of knowledge of advances in this narrow region of science, but also because certain fundamental statements of the optics of nonhomogeneous media and turbulence theory remained outside the field of vision of the authors. Of course, we must note that these articles [1-4] also indicated that the opinions of the authors on the phenomena they studied had undergone a noticeable evolution. Thus, while [2] considered only the influence of pressure pulsations, [3] additionally introduced temperature pulsations in the initial dependences, while [1] spoke also of fluctuations in the concentration of foreign impurities. However, such an evolution was not to be found in the final analytical computations and in the interpretation of the experimental data.

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*It was not clearly stated in [3] which bands were displaced nor was the manner in which temperature was controlled in the flow concretely specified. Since isothermicity to such a high accuracy must be controlled not on the average along any line, but for a distinct, extremely small flow volume, the scale of this volume and the technique of the optical measurements are of substantial interest.

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STABILITY OF TRANSONIC TWO-PHASE FLOW

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The nature of a singular point in the stability of one-dimensional transonic flow of a vapor–drop mixture in a channel of variable cross section is considered within the framework of a two-lquid hydrodynamical model. It is shown that the singular point in the case of any lags of the drops preserves the nature of a saddle inherent to homogeneous gas flow, shifting only towards the divergent part of the channel if the content of condensed phase is not too high. Here the transition of subsonic two-phase flow into supersonic flow is stable and the predominance of drop agglomeration over fragmentation and the positive curvature of the channel profile are stabilizing factors. The saddle nature of the singularity is possible only if the lag of the drops is not too high in the case of flows with a higher content of condensed phase. In the opposite case, the point at which the speed of sound is attained loses the nature of a saddle point.

A physical model and closed system of equations for the hydrodynamics of a coarse-dispersion vapor–drop mixture, taking into account the effects of relative motion and heat and mass transfer between the phases, and including seven first-order quasilinear differential equations (conservation equations) and ten final equations (four equations of state, four transfer equations, and two closure equations) has been proposed [1, 2].

It was proved that all the characteristic velocities of this type of one-dimensional nonsteady flow of a two-phase medium are real, and that the system of equations of one-dimensional nonsteady flow satisfies evolution conditions, and correctly states the problem with the initial data. From this point of view, the model of a two-phase medium can be considered physically justified.

Two of the six different characteristic velocities may change sign, passing through zero. The existence of vanishing velocity characteristic of one-dimensional nonsteady flow is due to the occurrence of singular points for the system of equations of the corresponding steady flow [3]. Flow in the neighborhood of a singular

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