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Nonequilibrium state of engineering systems

A. DOLINSKII[1], B. DRAGANOV[2], V. KOZIRSKII[2]

[1] Institute of Engineering Thermophysics NAS of Ukraine, Kiev; 03027, Kyiv, Zeljabov Str. 2a, Ukraine
[2]Department of Electric and Electro Technology, Educational and Research Institute of Energy and Automation,
National University of Life and Environmental Sciences of Ukraine, 03041, Kyiv, Geroyiv Oboroni Str. 12, Ukraine;
tel. 044-527-80-97, gorobetsv@ukr.net

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Abstract. We present a characteristic of nonequilibrium phenomena and describe a method of determining the interdependence of thermodynamic forces and irreversible processes caused by them.

Key words: nonequilibrium state, unstable systems, thermodynamic

Any engineering system has a certain technological structure, i.e., consists of a series of interrelated elements. Each structure on a certain j-th level is characterized by some collection of variables. In the twentieth century, due to profound experimental and theoretical investigations, the notions of physical laws have become wider. We should mention here, firstly, the discovery of nonequilibrium structures arising as a result of irreversible processes, where system relations are established naturally of themselves, secondly, the idea of the constructive role of time following from the discovery of nonequilibrium structures, and thirdly, the appearance of new postulates concerning dynamic, unstable systems. These discoveries have changed our concept of determinism [1].

It should be emphasized that at present the proposition of enthropy increment is by no means reduced to an increase in disorder because order and disorder appearance is explained by new, unique phenomena [3]. If the situation under study is far from and exist simultaneously, then, order and disorder prove to be tightly connected: one of them includes the other.

Our perception of nature becomes dualistic, and the basic concept in this perception is the idea of nonequilibrium state [2]. The matter is of nonequilibrium

status not only leading to order and disorder, but also making it possible to detect an equilibrium, then differential equations modeling this or that natural process become nonlinear, and analysis of a nonlinear equation, as a rule, is not reduced to a single type of solution. In this connection, a new solution can lead to changes in the space-time interpretation of the object or phenomenon under consideration.

Studying the interrelations between different physical phenomena does not cancel the phenomenological laws, existing within the framework of each phenomenon, but enables one to evaluate heuristically the possibilities of refinement and generalization of these laws and to understand their meaning more profoundly. These postulates are based on the principles of nonequilibrium thermodynamics [4...6], where the Onsager – Casimir reciprocal relation, established experimentally, has a fundamental character. This proposition, which can be called the fourth law of thermodynamics [7], is especially important in the modeling of real gas mixtures.

As the determining (rheological) relations supplementing the system of equations of heat and mass transfer, it is customary to apply the phenomenological relations of irreversible processes (Onsager relations):

$$I_k = \sum_{k=1}^{N} L_{kl} X_l, k = 1, 2, ..., N, \qquad (1)$$

where: N is the number of independent physical processes and L_{kl} is the matrix of phenomenological (kinetic) coefficients, connecting the fluxes L_k and thermodynamic forces X_1.

The fluxes and thermodynamic forces in (1) are, in the general case, tensor quantities of any rank. The physical meaning of kinetic coefficients can be clarified, within the framework of molecular-kinetic theory.

The number of nonzero kinetic coefficients in (1) is bounded by the Curie principle [4], according to which the components of fluxes (i.e., components of vectors along the coordinate axes) will depend not of all components of the thermodynamic forces. For example, in the case of an isolated system, processes of different tensor dimensionality do not interact between themselves. In addition, within the framework of Onsager relations, the Onsager – Casimir symmetry relations (the so-called reciprocity principle) are taken as an independent postulate [7]:

$$L_{kl}(B,\Omega) = \varepsilon_{kl}\varepsilon_{lk}L_{lk}(-B,-\Omega). \qquad (2)$$

Here: B is the magnetic induction, Ω is the angular velocity of rotation of the system, $\varepsilon_k = 1$ for even (energy, concentration) and $\varepsilon_k = -1$ for uneven (momentum density) microscopic parameters (even or uneven functions of particle velocities). For an isotropic nonrotating system in the absence of external magnetic field, the symmetry relation (2) takes a simpler form:

$$L_{kl} = L_{lk}, \qquad (3)$$

where: L_{ki} are scalar quantities.

We may consider the symmetry relations (2) and (3) as an empirically reliableaxiom, which is corroborated within the framework of statistical mechanics and by experimental data.

It should be emphasized that, in analyzing the hydrodynamic as well as the heat and mass transfer processes, the phenomenological approach (based on the postulates of nonequilibrium thermodynamics) enables one to obtain the defining relationships for the thermodynamic fluxes as well as algebraic formulas connecting the coefficients of molecular transfer and convenient for calculations.

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