CHEMICAL PHYSICS OF NON-EQUILIBRIUM PROCESSES: THE BASE FOR 21ST CENTURY TECHNOLOGIES

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Generators of low-temperature plasma are widely used in various branches of industry, and the technological processes developed on their basis have been long applied at numerous enterprises of our Republic. These processes are based on the arc discharge plasma or, as it is often called, thermal plasma, which is characterized by equilibrium distribution of thermal energy over the internal degrees of freedom of a plasma-forming gas. This means that at a given pressure the physical and chemical properties of such a plasma are determined by its temperature which can attain several thousand degrees in modern arc plasmatrons. As a matter of fact, the role of a low-temperature arc plasma generator reduces to rapid heating of a gas up to high temperatures, at which some physicochemical processes are intensified. The latter fact makes plasma technologies very energy-intensive so that the production based on them not always appears efficient from the energy viewpoint.

One of the, possible ways of raising the energy efficiency of plasma technologies is the use, where it is possible, a non-equilibrium plasma. The main distinct feature of non-equilibrium plasma systems as compared to equilibrium ones is the substantially non-equilibrium distribution of energy over the internal degrees of freedom of a plasma-forming gas, with the very sense of the notion of temperature in its classical traditional understanding being lost when applied to non-equilibrium systems. Each of the degrees of freedom of the particles composing a plasma-forming gas (translational, rotational, vibrational, and electronic) under non-equilibrium conditions is characterized by its own energy that may differ an order of magnitude from that it could have under equilibrium conditions at the same average plasma energy. A typical example of the device employing a non-equilibrium plasma is the popular daylight lamp, where, under the conditions of a low-pressure glow discharge, excitation of the electron degrees of freedom of the working gas molecules occurs, and the excited molecules lose an excess energy by radiation which we see every time we switch on the lamp. The typical, for the conditions of a glow discharge, distribution of energy over the internal degrees of freedom of the working gas molecules is as follows: the translational and rotational degrees of freedom are characterized by an average energy of an order of 0.03 eV, which in an equilibrium situation could correspond to the temperature close to a room one; the vibrational degrees of freedom have an average energy of about 0.3 eV, which in an equilibrium situation would correspond to a temperature of several thousand degrees; and, finally, the electronic degrees of freedom are characterized by an average energy of the order of several electron-volts, which in the case of equilibrium would correspond to a temperature of several tens of thousands of degrees. Here, the characteristic energy of free electrons and ions may differ from the average energy of the electronic degrees of freedom of the exciting gas molecules and attain tens of electron-volts.

Sustainment of a nonequilibrium state as strong as this in the gas is possible only at the expense of an external electric field "warming up" the electrons in a discharge that acquire the energy sufficient for ionization of the gas and provision of its conductivity as well as for exciting the internal degrees of freedom of the working gas atoms and molecules. Another widely known example of application of a nonequilibrium plasma is furnished by molecular gas lasers (the most popular of them are the lasers operating on vibrational-rotational transitions of the carbon dioxide and carbon monoxide molecules), in which the energy of the vibrational degrees of freedom, repopulated as against the equilibrium situation, is emitted in the form of a coherent infrared-range radiation.