In the present work, we consider the creation of a new jet–emulsion metallurgical process, in order to show that fundamental synergetic principles (the theory of self-organization) may be used in the design of such processes and in the control of the metal’s chemical composition by the organization of spatial dynamic dissipative structures.

Analysis of steel-smelting processes in terms of self-organization provides a somewhat different perspective on the control of such complex interconnected systems. The approach formulated in automatic control theory, which is basically intended for use in airplanes, involves separation of the intended and perturbed motion. That is evidently inapplicable in the design of smelting processes. If we pursue the analogy with airplanes, we see that the trajectories of the basic parameters in the smelting bath (the decarburization, heating, oxidation of the slag, etc.) may interact with one another. For example, change in the decarburization trajectory for any reason leads to change in the trajectories of metal heating and slag oxidation. Therefore, attempts to control any of these trajectories will perturb the others. In addition, it is unclear what the best trajectory of any of these interconnected parameters might be. In that case, the adoption of specified trajectories and attempts to maintain them by correcting any deviations will necessarily lead to nonoptimal results and may even impair the efficiency of the system. Conversely, if we employ the spontaneous internal motion of the system (its eigenfunctions) and select resonant control, the final results will be obtained with modest control expenditures. In that case, it is very important to take account of the internal feedback loops within the system.

The inapplicability of control methods designed for airplanes to systems such as smelting baths may be better understood on the basis of the fundamental texts on self-organization (synergetics) [1, 2]. However, the specific features of the application of self-organization to the control of complex interconnected systems remain to be determined.

To create a continuous smelting process has long been the dream of metallurgists. An important benefit of such a process, aside from the absence of intermediate losses of energy and raw materials, would be the presence of individual chambers (zones) for the necessary technological operations (decarburization, desulfurization, dephosphorization, etc.), as pointed out by Bigeev [3–5]. At that time, however, since smelting was undertaken in near-equilibrium conditions and consequently the chemical reactions were slow, great effort would have been required in the production of such chambers, and the overall system would be very capital-intensive.

However, by switching to gas suspensions and emulsions and employing synergetic principles, it is possible to create zones in the form of dynamic dissipative structures that exist only at the moment when the process occurs in the given conditions, rather than physically existing chambers. In that case, desulfurization is made possible by the enormous reactive surface at the gas bubbles, while dephosphorization is possible by controlling the granulometric composition of the batch supplied to the metal–slag boundary. The control of the carbon content will be considered later.

Before we show how steel with a carbon content lower than that of the hot metal may be produced in a
jet–emulsion reactor—in contrast to the Corex process, say—we will briefly explain the operating principles of the jet–emulsion reactor [6–9]. The basic components of the jet–emulsion reactor (Fig. 1) are the batch-supply system 1–5; reactor 6; the connecting channel with gas-dynamic shutoff 7; refining tank 8, which also serves as the first stage in wet gas cleaning; receiver 9 and cooling system 10 for the slag lining; slag tank 13, with granulator 14; fluidized-bed waste-heat system or smokestack-gas converter 17 (producing synthesis gas); and gas-purification system 18.

The basic process is as follows. Finely disperse batch, consisting of a mixture of oxides (of iron and other metals), together with solid reducing agents, is sent to the central zone of reaction chamber 6, where, on encountering oxygen fluxes, a high-density disk is formed. At this disk, dynamic interactions produce a very turbulent batch flux, and large surfaces for heterogeneous chemical reaction appear. Incomplete combustion of some of the coal, natural gas, or other reducing agent in the reactor (corresponding to the proportion of oxygen supplied) is accompanied by heating and partial reduction of the oxides.

We now consider the dissipative structures fundamental to this system.

The first dissipative structure is the high-density disk formed when the opposing disks collide. The practical utility of this effect was studied experimentally by using nitrogen to interrupt and disperse a hot-metal jet from a 100-t casting ladle in the foundry shop at OAO EVRAZ ZSMK, as shown in Fig. 2.

Thanks to the second dissipative structure, which incorporates this effect, we may create a reactor in which several basic principles of synergetics (the theory of self-organization) are implemented: large deviation from thermodynamic equilibrium; the least-