From the perspectives of training and research, models with concentrated parameters and models with distributed parameters represent two levels of simulation of the dynamics of the thermal state of blast furnaces. Using a hierarchical structure with a minimum of equations in the basic system ensures visibility – a prerequisite to success. The use of nonstandard numerical methods provides for stable calculations with a minimum number of steps in the subdivision and, thus, high speed in the calculation. The use of such models by technologists will improve the quality of the intuitive decisions that they make.

The fact that information technologies have now become an integral part of the control of blast-furnace (BF) operations changes the priorities in the activities of technologists involved in the operation of these units and requires a deeper level of understanding of the pertinent physical laws. Mathematical models can be one of the most effective tools for achieving such an understanding.

"Knowledge – is modeling. What does “know” mean in this case? It means knowing the structure of the subject system, its connections with other systems, and the changes it undergoes over time. Sometimes we have exact knowledge, in which case the model is detailed. Other times, we have only approximate knowledge. In this instance, we have only primitive models" (N. M. Amosov). In the present article, the word model has a dual meaning. On the one hand, in the human mind a model is a subjective entity and is poorly reproduced: “a thought that is uttered is a lie.” On the other hand, a model can also be a formalized and uniquely descriptive tool – a schematic, a formula, or a mathematical model (MM).

One of the most complex problems encountered in blast furnace operation – and a problem that is almost completely outside the framework of blast furnace theory – is studying the laws that govern the dynamics of the thermal state (TS) of the furnace and writing those laws in a form that will be suitable for a wide range of technologists. Solving this problem was the main objective in creating the models that are described in this article.

A model of the dynamics of the thermal state (TS) of blast furnaces was created in 1973–1975 [1] on third-generation Minsk-32, ES-1020, and ES-1022 computers. Although these were the fastest computers for their time, it turned out to be impossible to make practical use of the model on these machines. The attendant limitations were lifted only after the model was later reconstructed so as to be compatible with more modern computer hardware and software.

In the interim, researchers developed a simplified palliative variant that was realized on different models of microcomputers. This model has now been in use for more than 20 years as a training tool for blast-furnace engineers and operators in the training program given at Donetsk State Technical University (formerly KGMI, DGML) (the given variant of the model will henceforth be referred to as T1, in contrast to the more complete T2 version).

Trainer T1 is based on a dynamic model with concentrated parameters. In it, the blast furnace is represented as a single inertial first-order component with a time lag. Constant values are assigned to the dynamic characteristics in the different channels of T1 on the basis of empirical data in the literature. A great deal of experience has been gained with the use of T1, and improvements have been made to its content, service, and interface. The main algorithm has been supplemented by a
module that accounts for gasdynamic effects, simulates disturbances in the operation of the furnace, and models the charging operation. Another module that has been added describes random perturbations. The random-perturbation model (RPM) simulates actual operating conditions in the presence of uncontrollable inputs.

In previous versions of T1 (introduced as computer technology advanced), the results were usually produced in the form of a running table composed in text mode. Here, existing data in the table was permanently lost after each successive row was filled. The table showed values of 12 parameters over the last 20 hours of the simulation. As an auxiliary format, the tabular data was also represented in the form of graphs constructed for selected moments (the graphs covered 5 parameters for a 40-h period). It is important to note that even such a primitive variant as this markedly improved the students’ training and their preparation for practical use of the information.

The T1 model was originally viewed as a temporary variant that was to have been replaced by T2 as it was mastered. However, use of T1 showed that it has its own advantages and that it makes sense to continue using it. Thus, it was recently updated (Windows, Delphi). The main form of representation of the data is graphical. The information is presented in the dynamic regime, with a significant increase in scan time and the number of parameters. The running tables were also made more detailed.

_Trainer T2_ was constructed on the basis of a dynamic model with distributed parameters [2]. The main difficulty encountered in creating it has been that there has not been enough data to fully describe phenomena. Here, it is assumed that, regardless of the complexity of the system, any problem can be solved if the correct initial control data and coefficient values are entered into the training module. In fact, the modeling process itself immediately helps refine inadequate data already in the module. “To construct a theory, it is necessary to perform an experiment. However, to know which experiment to perform, it is necessary to construct a theory.” (physicist I. Pomeranchuk).

There are two actual problems – the problem of visibility and the problem of keeping the computational procedures stable. The first problem is addressed by creating a hierarchical structure and making its upper level as large as possible, while the second problem is resolved by using nonstandard numerical methods. The allocation of work among production-process engineers, mathematicians, and programmers is often accompanied by a critical loss of information at the points where information is exchanged between these groups. In our case, the problems of creating a suitable algorithm and program was solved using a process-based feedback loop.

**Structure of the model.** The three most important phenomena in the countercurrent flow that we are concerned with here are the reduction of iron, the gasification of carbon, and heat exchange. Having chosen one parameter for each of the two flows in the system, we obtain six equations: three for the gas and three for the charge. Six is the minimum number of equations for which the blast-furnace process is sustained (the process would be terminated without any one of these equations).

Besides visibility, such an approach offers the advantage of relegating all of the debatable and little-studied aspects of the given problem to the lower levels of the hierarchy. The highest level is not simply the path to the algorithm, but also a transparent representation of the course of countercurrent heat exchange that is readily accessible both to students and to furnace operators and engineers. Acquiring a good familiarity with the hierarchical model improves the qualifications of all of them, regardless of whether they will be using the formulas to calculate specific values of the parameters or simply making use of the final results.

**Main system of equations:**

1) \( \frac{\partial Y}{\partial x} = 400(v_r - v_g)/W_c \) is the rate of accumulation of oxidized gases and is proportional to the difference between the rate of reduction of iron and the rate of gasification of carbon;

2) \( \frac{\partial V_a}{\partial x} = 400(v_g - v_{rc})/W_c \) is the rate of accumulation of the sum of the active gases and is proportional to the sum of the rate of gasification of carbon and the rate of reduction of iron by carbon from the melt;

3) \( \frac{d\Omega}{d\tau} = -(v_r + v_{rc}) \) is the rate of decrease in the degree of oxidation of the iron and is equal to the sum of the rates of the two types of iron reduction taking place inside the furnace;

4) \( \frac{dZ}{d\tau} = v_g + v_{rc} \) is the cumulative rate of direct reduction and is equal to the sum of the rate of gasification of carbon and the rate of reduction of iron by carbon from the melt;

5) \( \frac{\partial t_g}{\partial x} = -(t_g - t_C) + \delta c_{wgr}/W_g \) is the rate of cooling of the gas and is proportional to the difference between the temperatures of the flows, with a correction for the Kirchhoff effect for the water-gas reaction (WGR);