Information-modeling system for monitoring heat losses in the lower part of a blast furnace

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Abstract
The article presents a structure of the algorithm and mathematical and software systems. The general characteristics of the algorithm for determining heat losses in the hearth of a blast furnace based on the use of the heat balance of the lower zone are presented. External heat losses in the process of melting occurring through the tuyere belt, barrel, and bosh, are determined by the difference between the input and output components of the zonal heat balance for the lower part of heat transfer. The determination of heat losses by the heat balance in the lower heat transfer part allows their value to be estimated according to the current information about the operation of the furnace under specific raw materials and operating parameters. The information support of the system is presented, the software architecture is described, the characteristics of the software modules are given, and fragments of its work are illustrated. The information modeling system is distinguished by taking into account the basic physical and chemical laws of the processes of the control object, the principles of system analysis, and the use of modern principles for the development and construction of mathematical models and software. Heat loss control is necessary to assess the condition of the blast furnace refractory lining and rational gas distribution, as well as to adjust the coke rate.

Keywords Software · Blast furnace · Zone heat balance · Heat loss · Architecture · Web application

Control of heat losses during blast furnace melting is considered the third most crucial means to control and automate the blast-furnace process, following the control of the charge and quality of iron ore raw materials and coke, as well as the processing technology of smelting products [1–7]. Heat losses vary over the course of the blast furnace (BF) operation due to factors such as flame erosion of the lining, the formation of scull with the potential for its destruction, and the development of either peripheral or axial gas streams. For example, in Japan, in order to conserve coke, the excessive development of the peripheral gas stream is controlled and eliminated using heat removal data from barrel and bosh refrigerators [8].

The main heat losses occur in the lower part of the blast furnace, which determines its performance, while their magnitude depends on the specific design and operating parameters of the furnace [5–13]. During melting, external heat losses occurring through the tuyere belt, barrel, and bosh, are determined as the difference between the input and output components of the zonal heat balance for the lower heat exchange part [14–16]. A block for calculating the heat balance of the lower heat transfer part included in the mathematical model of the UrFU-MMK [17, 18] blast furnace process allows the input and output heat balance components to be identified based on the current data of the melting process and the calculation results to be analyzed, along with forecasting

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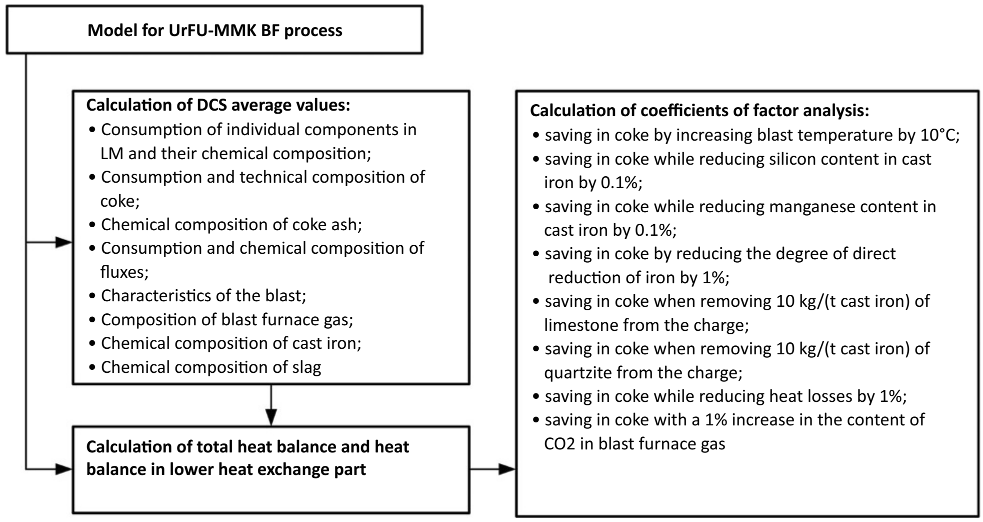

Fig. 1 Algorithm for calculating the heat balance of the lower heat transfer part of a blast furnace

a decrease in coke rate when varying the parameters of the BF operation. Through the analysis of the heat balance of the lower heat transfer part, it is possible to determine the heat losses in this zone of the furnace and evaluate correction coefficients when blast furnace conditions are varied, such as the composition of cast iron, blast temperature, humidity, removal or addition of various additives into the loaded charge, as well as changes in heat losses during blast furnace melting.

During the development of an information-modeling system for monitoring heat losses in the hearth of a blast furnace, the following steps are implemented:

– functional modeling of the system and development of architecture, mathematical, and information support to the system;
– selection of technology and software development and implementation of the design module;
– implementation of the web application for the system;
– debugging and testing of the software.

The methodology used in the design of the system is based on the principles of structural analysis and design of IDEFO [19]. The functional model developed using the Ramus software [20] contains 35 blocks at four levels of decomposition. This model defines the main functions and relationships between individual functional blocks in the system, control actions, and mechanisms for performing each function.

The algorithm for calculating heat losses in the lower part of the blast furnace is shown in Fig. 1.

The input components of the heat balance are as follows.

1. Amount of heat released during the combustion of coke carbon fed to the tuyere zones.
2. Amount of heat introduced into the furnace by heated blast.
3. Amount of heat produced by the conversion of natural gas.
4. Amount of heat generated during slag formation. The calculation of this component is carried out only for the case of loading “raw” limestone into the furnace.
5. Amount of heat introduced into the lower zone of the furnace by heated charge materials. When calculating this component of heat input, the rates of charge materials, their heat capacity, and the temperature of the standby zone are taken into account.

The output components of the heat balance are as follows.

1. Heat consumption for direct reduction of iron oxides.
2. Heat consumption for direct reduction of cast iron impurities ([Si], [Mn], [P]) and desulfurization of cast iron.

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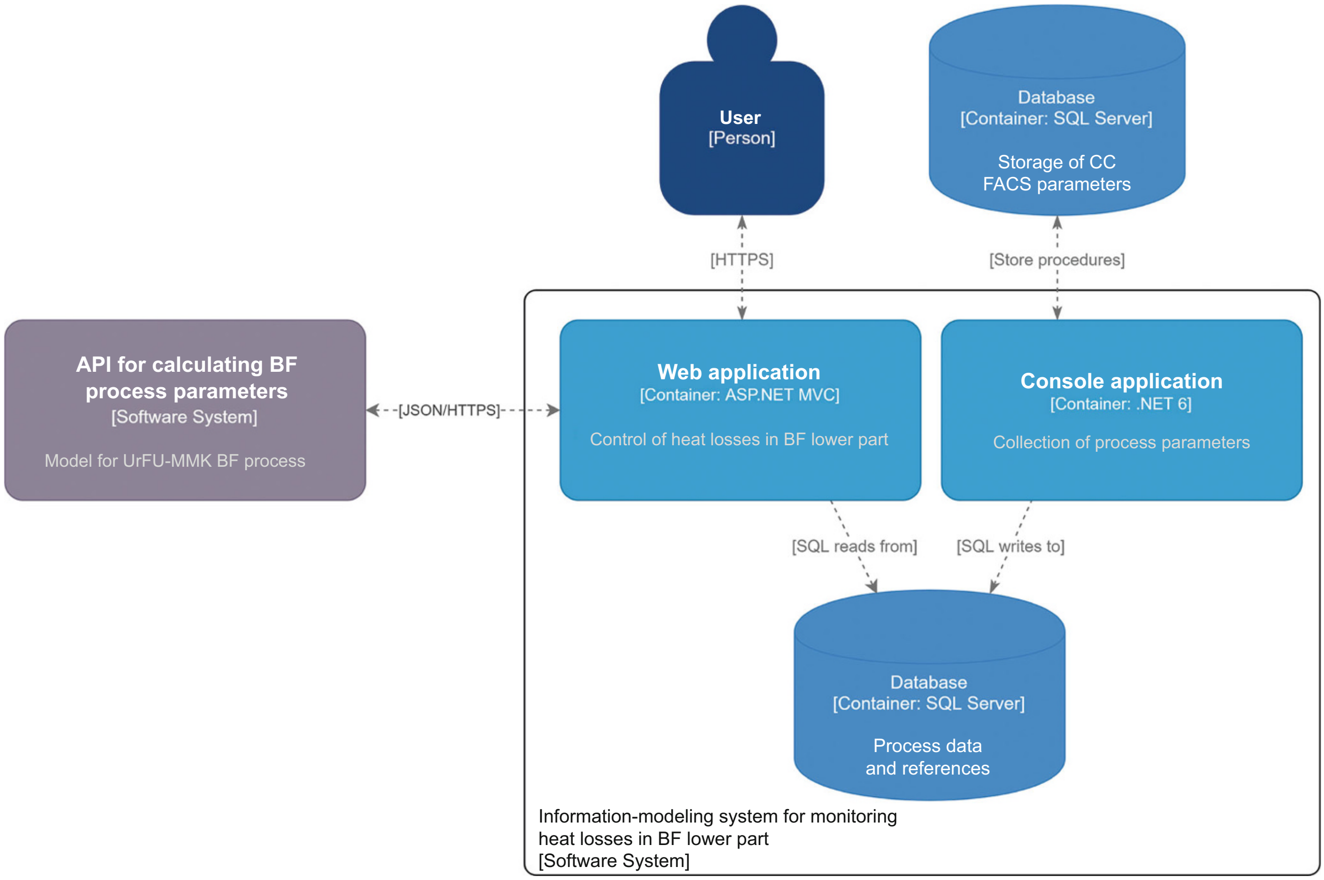


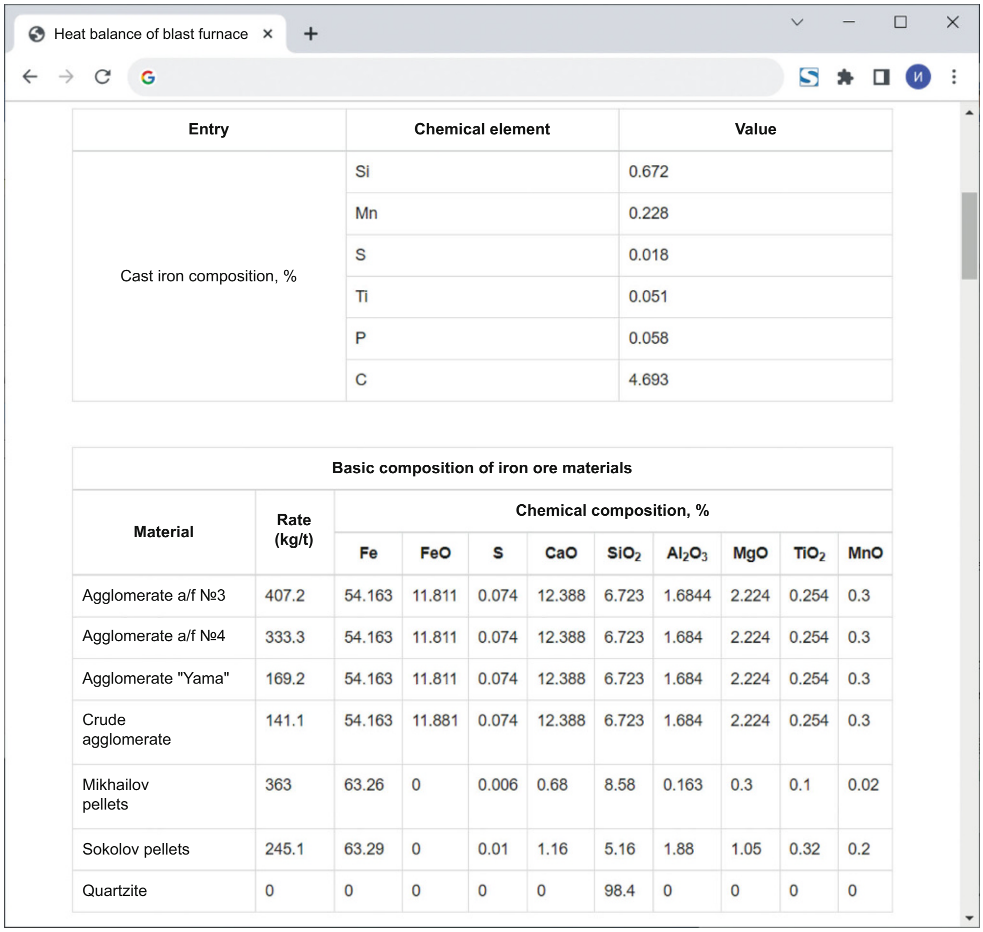
Fig. 2 Architecture of information-modeling system for monitoring heat losses in the lower part of a blast furnace

3. Heat consumption to compensate for the reduction of iron oxides with hydrogen.
4. Heat removal by cast iron.
5. Heat removal by slag.
6. Heat removal by gas from the lower heat exchange part.
7. Heat consumption for decomposition of blast moisture.
8. External heat losses during melting determined as the difference between the input and output components of the zonal heat balance for the lower heat exchange part.

Calculation of correction coefficients for factor analysis

The calculation of the heat balance of the lower heat transfer part allows the savings in coke to be determined, which can be achieved by varying the heat consumption for any given process. To do this, the heat transfer from coke carbon is determined based on the established blast smelting parameters, while the variation in the coke rate is determined by the known heat consumption of any given process:

– an increase in blast temperature by 10 °C;
– reduction of silicon content in cast iron by 0.1%;
– reduction of manganese content in cast iron by 0.1%;
– reduction of the degree of direct reduction of iron by 1%;
– removal of 10 kg/(t of cast iron) of limestone from the charge;



Entry	Chemical element	Value
Cast iron composition, %	Si	0.672
	Mn	0.228
	S	0.018
	Ti	0.051
	P	0.058
	C	4.693

Basic composition of iron ore materials											
Material	Rate (kg/t)	Chemical composition, %									
		Fe	FeO	S	CaO	SiO_2	Al_2O_3	MgO	TiO_2	MnO
Agglomerate a/f №3	407.2	54.163	11.811	0.074	12.388	6.723	1.6844	2.224	0.254	0.3
Agglomerate a/f №4	333.3	54.163	11.811	0.074	12.388	6.723	1.684	2.224	0.254	0.3
Agglomerate "Yama"	169.2	54.163	11.811	0.074	12.388	6.723	1.684	2.224	0.254	0.3
Crude agglomerate	141.1	54.163	11.881	0.074	12.388	6.723	1.684	2.224	0.254	0.3
Mikhailov pellets	363	63.26	0	0.006	0.68	8.58	0.163	0.3	0.1	0.02
Sokolov pellets	245.1	63.29	0	0.01	1.16	5.16	1.88	1.05	0.32	0.2
Quartzite	0	0	0	0	0	98.4	0	0	0	0

Fig. 3 Fragment of a web page visualizing blast furnace operation parameters

- removal of 10 kg/(t of cast iron) of quartzite from the charge;
- reduction of heat losses by 1%;
- an increase in the CO_2 content in the blast furnace gas by 1%.

The software for the information-modeling system to monitor heat losses in the lower part of the blast furnace is a cross-platform web application developed using the C# programming language. This application is built on the software platform .NET 6 with the help of Core MVC framework and Entity Framework [21]. The web application, having a three-level architecture, consists of a presentation level (client), a model level (application server), and a database level. SQL Server is used as a database management system (DBMS). The architecture of the developed software in C4 notation is shown in Fig. 2.

The software includes two containers: a console application and a web application. The console application, which runs on a schedule, is designed to gather data on various parameters of the technological process (such as blast characteristics, composition and properties of charge materials, and composition and properties of liquid melting products) from the database server of the control center of the factory automation control system (CC FACS). The obtained and calculated parameters averaged by days, weeks, and months are stored in the system database.

The web application includes the following main functions: selection of the period and visualization of the blast furnace operation parameters within the selected period; visualization of the calculation of the total heat balance and heat balance in the lower part of the furnace; calculation of the coefficients for factor analysis to assess variations in coke rate when certain process parameters are adjusted.

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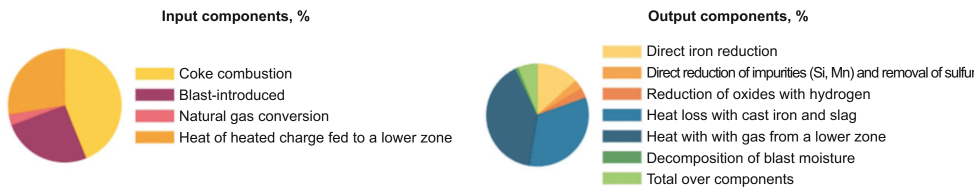
Input components		
Entry	**kJ/kg**	**%**
Coke combustion	2616	43.1
Blast-introduced	1572	25.91
Natural gas conversion	210.9	3.48
Heat of heated charge fed to a lower zone	1670	27.52
Total heat input	6069	100

Output components		
Entry	**kJ/kg**	**%**
Direct iron reduction	801	13.2
Direct reduction of impurities (Si, Mn) and removal of sulfur	205.7	3.39
Reduction of oxides with hydrogen	208	3.43
Heat loss with cast iron and slag	1972	32.49
Heat with with gas from a lower zone	2403	39.6
Decomposition of blast moisture	85.48	1.41
Total over components	5675	
Heat losses of furnace	394	6.49
Total		100



Factor analysis coefficients	
Coefficient, unit	**Value**
Saving in coke rate by increasing blast temperature by 10°C, %	1.42
Saving in coke rate while reducing heat losses by 1%, kg/t cast iron	5.52
Saving in coke rate while reducing silicon content in cast iron by 0.1%, kg/t cast iron	2.41
Saving in coke rate while reducing manganese content in cast iron by 0.1%, kg/t cast iron	0.47
rate while reducing the degree of direct reduction (rd) by 0.01, kg/t of cast iron	2.71
Saving in coke rate when removing 10 kg/(t cast iron) of limestone from the charge, kg/t cast iron	2.12
Saving in coke rate when removing 10 kg/(t cast iron) of quartzite from the charge, kg/t cast iron	1.15
Saving in coke rate with an increase in CO2 content in blast furnace gas by 1%, kg/t cast iron	3.41
Variation in furnace performance to an increasing O2 content in blast by 1%, %	2.34

Fig. 4 Fragment of a web page visualizing the calculation of heat balance in the BF lower part

The visualization component for the blast furnace operation parameters during the reference period allows the variations in user-specified DCS parameters to be reviewed for the selected blast furnace and a specified period. The information is displayed in tabular form. A fragment of the web page of this feature is shown in Fig. 3.

The calculation of the total heat balance and heat balance in the lower part of the furnace, as well as the computation of correction coefficients for factor analysis, are carried out based on the operating parameters specified by the user for the selected period, which include blast characteristics, composition, and properties of charge materials, as well as the composition of liquid melting products.

A fragment of a web page visualizing the calculation of heat balance in the BF lower part is shown in Fig. 4. For user convenience, the calculation results can be printed directly from the browser.

Therefore, the developed software for the information-modeling system to monitor heat losses in the blast furnace offers:

– calculation of heat losses in the lower part of the blast furnace, input and output components of the heat balance, as well as a set of intermediate indicators for any selected operation period of the blast furnace;
– numerical and graphical display of calculation results;
– storage (removal) of source datasets in a database;
– printout of the results using browser functions.

Conclusion

1. By using advanced methodology, computer technologies, and software, the software for the control system of heat losses in the hearth of a blast furnace was developed to estimate their value based on the current data on the furnace operation in terms of specific raw materials and mode parameters.
2. The information-modeling system takes into account the basic physicochemical principles of the main processes occurring in the control object, as well as the principles of system analysis. In addition, it involves modern principles for developing and constructing mathematical models and software.

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