Using of Intelligence Analysis of Technological Parameters Database for Implementation of Control Subsystem of Hot Blast Stoves Block ACS

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Abstract

One of the main trends in the development of automation control systems of blast-furnace production units is the use of the intelligence analysis of the data in order to identify new dependencies between technological parameters. In automated control of the heating of the hot blast stove checkerwork, its thermal state depending on the different duration of mode switching and heat loss to the environment is not taken into account.

The goal of the work is the application of the intelligence analysis of technological information from a database about the state of the hot blast stove during the periods of its switching from mode to mode for timely adjustment of the set values of parameters in controlling of the hot blast heating.

An algorithm and program have been developed for extracting from the archive database the values of the parameters of technological process of heating the hot blast to analyze the states of the hot blast stove when it switches from mode to mode. The structure of an automatic control system for hot blast stoves block using the subsystem of the intelligence analysis of the data has been proposed, it is based on the algorithm with the capability to adjust the operating modes of the block.

The application of the proposed intelligence analysis algorithm in the automatic control system will allow to increase the hot blast temperature without significant capital investments in the reconstruction of the hot blast stoves block.

Keywords 1

Intelligence analysis, database, algorithm, software, hot blast stove, mode

1. Introduction

Most of the hot blast stove blocks are equipped with automatic control systems, in which the values of technological parameters are recorded in a database which allows to study the state of the hot blast stove over a long period of operation, including the state of the checkerwork when changing its operating modes. At the same time, the actual problem is the stabilization of the hot blast temperature at the set value, taking into account the aging of the hot blast stoves.

A review of scientific publications over the past few decades related to the automation of blast-furnace production units shows that one of the main trends in the development of control systems is the use of the intelligence analysis in order to identify new dependencies between technological parameters.

The goal of the work is the application of the intelligence analysis of technological information from a database about the state of the hot blast stove during the periods of its switching from mode to mode for timely adjustment of the set values of technological parameters in controlling of the hot blast heating.

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2. Formal problem statement

To intensify blast furnace smelting, hot blasting is supplied to the furnace, which is heated in the block of hot blast stoves to a temperature of 1200-1300 °C. The required value of the blast temperature is determined by the blast furnace technology. The hot blast stove (hereinafter referred to as HBS) is a regenerative unit of periodic action up to 40 m high. During the “on-gas” mode, the heat from the combustion of the fuel gas is transferred to the refractory checkerwork. During the “on-blast” mode, the heat from the checkerwork is transferred to the blast. A standard block of hot blast stoves (hereinafter referred to as HBSB) consists of three to four units. The main task of the HBSB control system is to maintain the hot blast temperature at a given value.

The operating mode of the hot blast stoves is determined by the following set of parameters: fuel consumption, air consumption, dome temperature, maximum smoke temperature in the under-checkerwork unit, blast consumption, time mode, i.e. the duration of the blasting period (hereinafter referred to as “on-blast”) and the heating period (hereinafter referred to as “on-gas”), the duration of the separation period, when gases do not move through the hot blast stove, as well as the “on-switch” mode [1]. The main operating modes of the block: sequential, pair-parallel, mixed, parallel.

The operating modes are determined by the parameter chart, in which the time characteristics of the “on-gas” and “on-blast” modes, of the transfer of the hot blast stove from mode to mode are determined. In this case, the deviation of one of the parameters of the parameter chart from the established ones leads to the change in the operating modes of all hot blast stoves and fluctuations in the value of the blast temperature [2, 3].

Consequently, the task of controlling the HBSB is to implement the adopted parameter chart with a minimum consumption of blast furnace gas, a high-calorific additive, and combustion air in such a way that the maximum possible hot blast temperature is achieved.

The main disturbing influences on the hot blast stove operation:

- the blast furnace gas calorific value – it changes during the day by 20-30% which directly affects the heating time of the checkerwork;
- the incorrect fuel-air ratio due to inaccurate air flow control or its complete absence;
- the time of switching the hot blast stove from mode to mode - very often the switch of the hot blast stove from mode to mode is carried out in the remote control of the gasman / operator, which affects the duration of the switching.

Most of the hot blast stoves blocks are equipped with automatic control systems (ACS) of the dome temperature, the fuel-to-air ratio, stabilization of the hot blast temperature, at the same time, switching of modes is performed by operators remotely using the appropriate switches on the control panel. The values of technological parameters are recorded in the current database, and then in the archive, which allows to study the state of the hot blast stove when changing its operating modes.

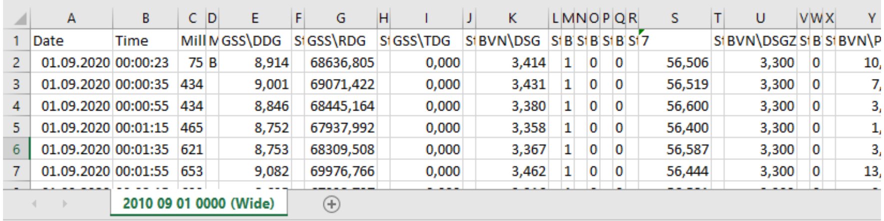
To build graphs of changes in the main technological parameters (trends), the values are taken mainly from the archive database.

In the automation system of the studied block of hot blast stoves, the values of technological parameters are recorded in two types of database files in *.dbf format. In a file of the first type (Fig. 1) 175 values of technological parameters of four hot blast stoves of the block are recorded every 10 seconds for the whole day. One file contains over 1.5 million records. The data is stored in a rather inconvenient way - in a column. The file of the second type, the so-called "wide" base (Fig. 2), already has several dozen of columns of data, which greatly simplifies the work, but the data recording period is now 20 seconds.

	A	B	C	D	E	F	G	H	I
1	Date	Time	TagInc	Value	Status	Marker	Internal		
2	12.10.2019	00:00:20	0	5,326		B			
3	12.10.2019	00:00:20	1	1,000		B			
4	12.10.2019	00:00:20	2	10,327		B			
5	12.10.2019	00:00:20	3	72429,563		B			
6	12.10.2019	00:00:20	4	0,141		B			
7	12.10.2019	00:00:20	5	6,563		B			

2019 10 12 0000

Figure 1: Database of the common type



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Date	Time	Mill	M	GSS\DDG	S	GSS\RDG	S	GSS\TDG	S	BVN\DSG	S	B	S	B	S	B	S	7	S	BVN\DSGZ	S	B	S	BVN\P
2	01.09.2020	00:00:23	75	B	8,914		68636,805		0,000		3,414		1		0		0		56,506		3,300		0		10,
3	01.09.2020	00:00:35	434		9,001		69071,422		0,000		3,431		1		0		0		56,519		3,300		0		7,
4	01.09.2020	00:00:55	434		8,846		68445,164		0,000		3,380		1		0		0		56,600		3,300		0		3,
5	01.09.2020	00:01:15	465		8,752		67937,992		0,000		3,358		1		0		0		56,400		3,300		0		1,
6	01.09.2020	00:01:35	621		8,753		68309,508		0,000		3,367		1		0		0		56,587		3,300		0		3,
7	01.09.2020	00:01:55	653		9,082		69976,766		0,000		3,462		1		0		0		56,444		3,300		0		13,

2010 09 01 0000 (Wide)

Figure 2: Database of the "wide" type

In this case, the temperature of the hot blast is recorded in a separate file of the "wide" database with an interval of 10 seconds.

In the base of the first type, there are certain variables corresponding to the “on-gas” mode and the “on-blast” mode, therefore it is easy to determine in which of the three modes the HBS is located.

However, in the "wide" database there is only one variable characterizing the “on-blast” mode, which complicates the determination of the “on-gas” mode and the “on-switch” mode. In doing so, nothing is written to this variable for one of the hot blast stoves of the block.

Throughout the entire campaign of the hot blast stove, its technical state deteriorates, the thermal characteristics of the checkerwork change, it requires adjustments to the control algorithms of the automation system.

The authors propose a new approach that allows to analyze in real time the state of the checkerwork of the hot blast stoves when they are switched from mode to mode using the current technological information recorded in the database.

To achieve this goal, it is necessary to solve the following tasks: to develop an algorithm for the intelligent analysis of the technological base and its software implementation, to conduct a study of changes in the temperatures of the dome and exhaust gases during periods of change in operating modes, to develop the structure of the hot blast stove checkerwork heating ACS based on the subsystem of the intelligence analysis of the data.

The authors have developed an algorithm that allows to accurately determine in which mode the hot blast stoves are according to the values of other technological parameters. The following parameters were used: gas consumption for combustion; combustion air pressure; parameter of the “on-blast” mode.

3. Literature review

In paperwork [4], an intelligent expert system is considered, which automatically sets the fuel gas and air flow rates for heating the checkerwork of a hot blast stove and when the set temperature of the flue gases is reached, automatically calculates the duration of the “on-gas” period and automatically sets the gas flow rate in accordance with the estimated duration.

Work [5] proposes a predictive control scheme for hot blast stoves using a linear model based on the results of experiments with a step-by-step response on a detailed dynamic model of the process. The model is also supplemented with an integrated disturbance model. The developed optimizing control scheme allows to minimize energy consumption in hot blast stoves.

The authors of [6] have developed two models that allow predicting the consumption of blast furnace gas by a block of hot blast stoves. The first model is the network Echo-state model, which is more complex and sensitive to variations in operating methods. The second model is a simple switch model that requires no training and is very easy to use. The implementation of the proposed models contributes to both the reduction of the exploitation of natural resources, for example, natural gas, and the reduction of the facility's impact on the environment.

In work [7], it is shown a modern strategy for heating a hot blast stove based on fuzzy clustering of C-means. The strategy is a dynamic management of the gas-air ratio based on cluster analysis of a large amount of production data. Compared with the traditional combustion control method, the improved method has better optimization effect and better stability.

The authors of [8] presented a self-correcting computer system for controlling the temperature of a blast-furnace blast, consisting of three separate subsystems: calculation of the gas consumption ratio; dome temperature control; regulation of combustion gas temperature.

The paper [9] proposes the use of a neural network in the optimization of fuel consumption control and stabilization control of the dome temperature and the temperature of the combustion gases. Using the neural network decoupling control technique, the fuel consumption control in the hot blast stove was disabled. To obtain the ability to control the neural network decoupling, the authors used a direct link compensator in the structure with the HBS neural network.

In the course of an intelligent study of the control philosophy used for the heating cycle of a hot blast stove, it became obvious that the combustion process is not efficient enough and there are ways to improve it [10]. The actual aggregation and intelligent evaluation of production data allowed the identification of measures to increase the temperature of the hot blast. A new control system was developed and implemented that allows combustion to be regulated depending on the current chemical compositions of the blast furnace and coke gases, the required combustion temperature and the correct air-to-fuel ratio, maintaining a minimum oxygen level in the flue gases to achieve the maximum dome temperature.

In the study of difficult operating conditions of a hot blast stove [11], a hybrid intelligent algorithm is used for preliminary clustering processing of technological data sources and obtaining reliable forecasting results. Experimental results show that the algorithm has good convergence and stability. The improved predicted Markov value is close to the actual value and in line with the target value.

Article [12] proposes a new deep memory Echo-state network (DMESN) for predicting the flue gases temperature. Data preprocessing, including deviation of blowouts, missing data processing and lag time computation, is performed to obtain the best dynamic characteristics of the dataset. To increase the accuracy of prediction, an improved structure of the hidden layer is proposed, which consists of two parts: the formation of an Echo-state and the formation of a hidden state.

4. Development of the Algorithm and Program Description

The complexity of information processing is that in databases of various types, due to the imperfection of instrumentation installed on hot blast stoves, not all parameter values are presented for the same period of time, and part of the parameters are recorded with a period that does not coincide with the record period in another database. To process such huge and complex amount of information, it is necessary to create a specialized software tool for opening a database of two types, extracting the necessary data from them, extrapolating parameter values from one database to synchronize time intervals with the records of another database. The result should be an array of data for data mining of the parameters and operating modes of the hot blast stove. For each HBS of the block, a separate MS Excel file should be generated, containing three tabs with the corresponding information about the “on-gas” mode, the “on-blast” mode and the “on-switch” mode of the HBS from mode to mode.

In the base of the first type, there are corresponding variables VN\N and VN\D to determine the “on-gas” mode and the “on-blast” mode, so there was no difficulty in dividing the database into three operating modes of hot blast stoves.

Preliminary statistical processing of the database showed that the values of technological parameters were correctly recorded in the database. Fig. 3 shows a block diagram of the analysis of the base of the first type.

However, in the database of the second type, there is one variable describing the “on-gas” mode VN\D, while the open hot blast valve corresponds to the value VN\D=1, and the closed valve corresponds to VN\D=0.

Based on the valve switching cyclogram, if the parameter values are correctly recorded in the database, the periods can be determined as follows:

1. The “on-blast” mode: VN\D=1 - the hot blast valve is open, the blast is supplied for heating to the hot blast stove checkerwork; VN\RSG=0, fuel gas is not supplied for combustion in the hot blast stove burner, gas consumption is 0; VN\PVOZ=0, combustion air pressure is 0, air flow is 0.
2. The “on-gas” mode: VN\D=0 the hot blast valve is closed, the blast is not supplied for heating to the hot blast stove checkerwork; VN\RSG>0, fuel gas is supplied for combustion in the hot blast stove burner, gas consumption is more than 0; VN\PVOZ>0, air is supplied for combustion, air consumption is more than 0.

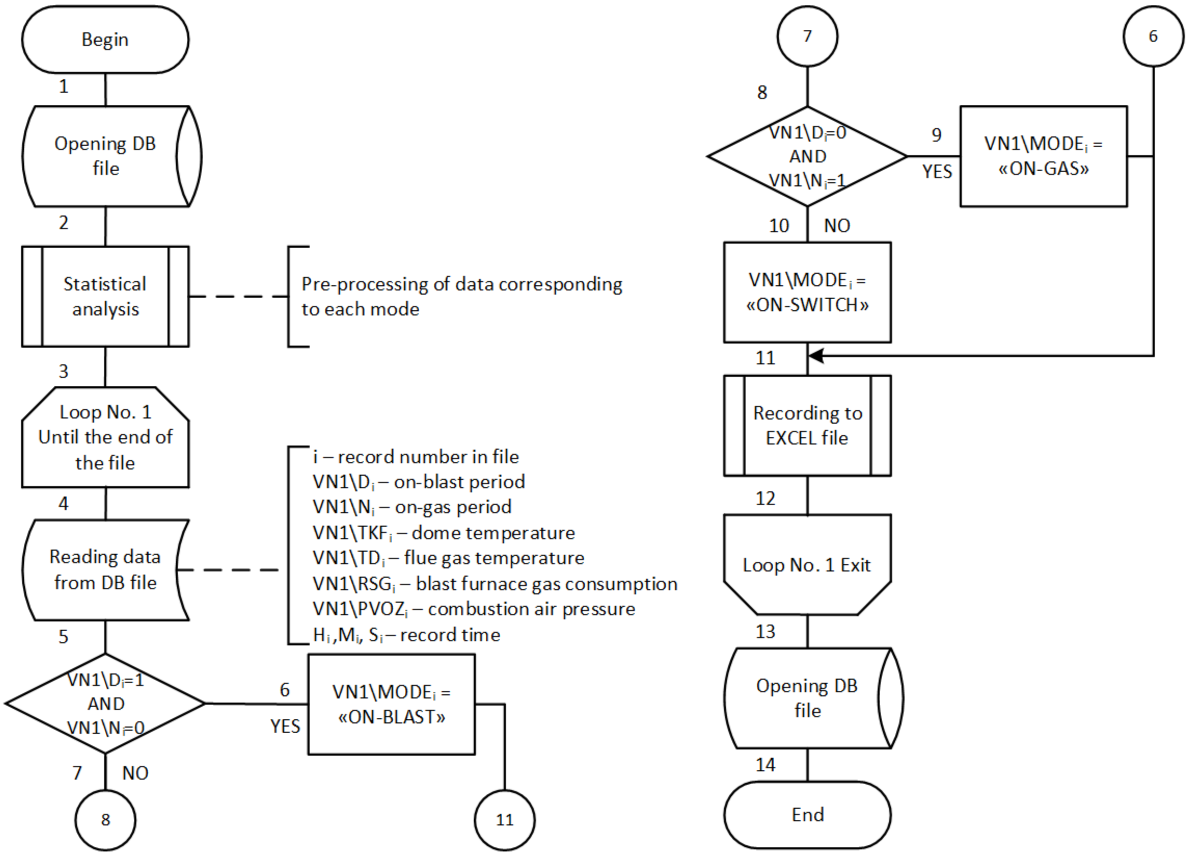


Figure 3: Block diagram of the analysis of the base of the first type

3. The "on-switch" mode of the hot blast stove from mode to mode: VN\D=0 when switching the hot blast valve must be closed; VN\RSG=0, fuel gas is not supplied for combustion in the hot blast stove burner, gas consumption is 0; VN\PVOZ ≥0, at the beginning of switching from the "on-gas" mode to the "on-blast" mode, air is supplied to the ventilation of the hot blast stove, the air flow is more than or equal to 0.

When compiling the algorithm for dividing the database into modes, preliminary analysis revealed incorrect records of parameter values, which are summarized in Table 1.

Table 1
Analysis of the "wide" database

Parameter	Mode	VN1	VN2	VN3	VN4
		Current value			
VN\D	«On-blast», «On-switch»	**0**	1	1	1
	«On-gas»	0	0	0	0
VN\RSG	«On-blast», «On-switch»	**0<CV<8000**	**0<CV<8800**	**0<CV< 6000**	0
	«On-gas»	>0 MIN=13030 AVG=30666 MAX=41535	>0 MIN=8968 AVG=18732 MAX=28059	>0 MIN=11791 AVG=34905 MAX=37951	>0 MIN=13919 AVG=43752 MAX=52552
VN\PVOZ	«On-blast», «On-switch»	**0<CV<0,106**	0	0	**0<CV<0,049**
	«On-gas»	>0 MIN=1,211 AVG=3,841 MAX=6,078	>0 MIN=2,422 AVG=3,432 MAX=4,672	>0 MIN=0,572 AVG=1,333 MAX=2,138	>0 MIN=0,985 AVG=2,205 MAX=2,506

Fig. 4 shows a block diagram of the analysis of the second type base.

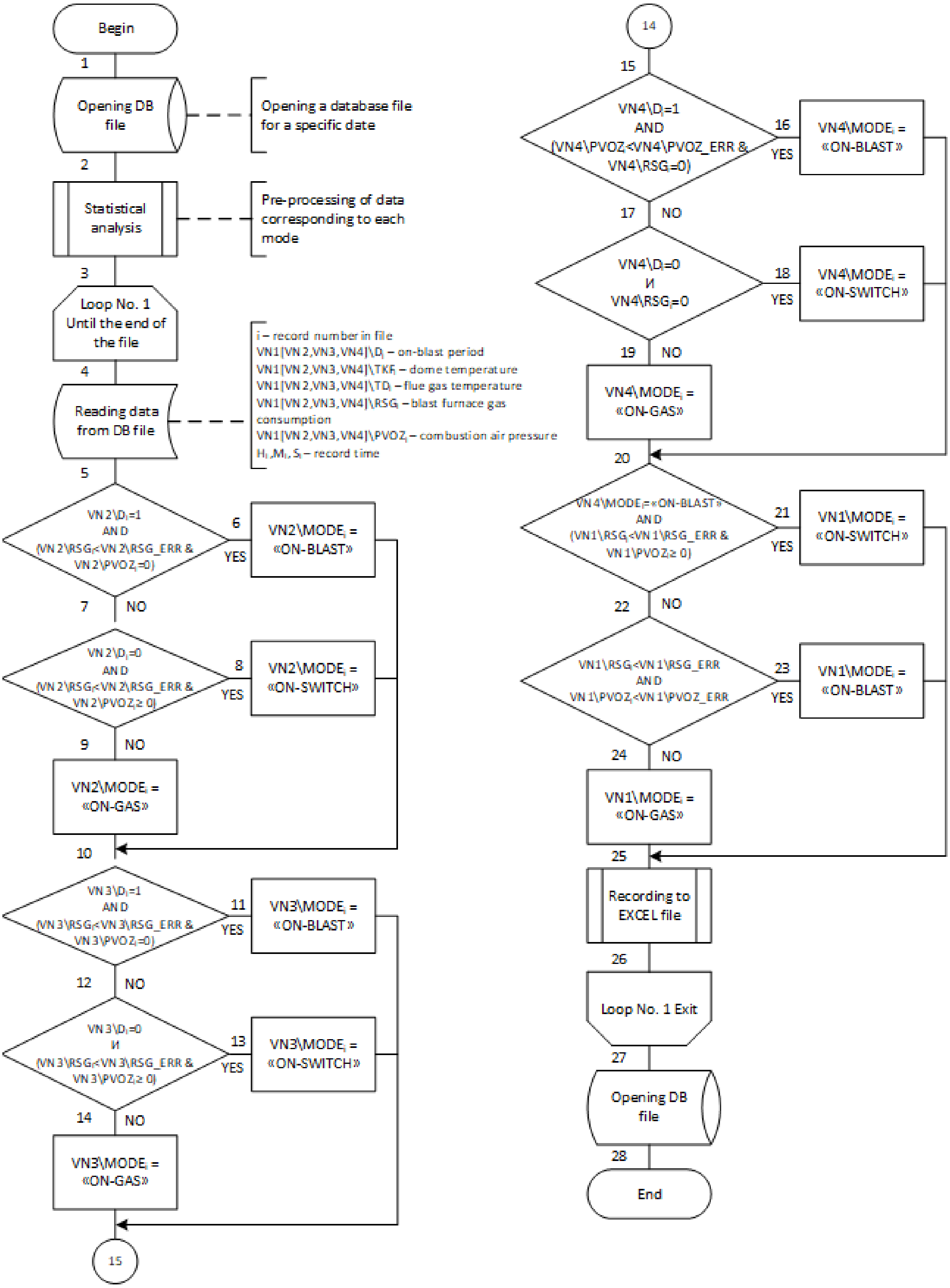


Figure 4: Block diagram of the analysis of the second type base

It was decided to implement the program in the modern programming environment IDE MS Visual Studio 2019 in the object-oriented programming language C #, which is quite simple, but with a lot of convenient features and extensions for various tasks. The program connects to the directory in which the database files are stored, extracts the necessary information from it and submits it in an easy-to-read form to a new structured database or to an MS Excel file for further intellectual processing.

When developing the program as a provider for connecting to the database and extracting the necessary records from it, the database management system MS Visual FoxPro was used - an environment for developing database systems, including an object-oriented relational DBMS and a programming language for developing database applications and a system for reporting [13].

ClosedXML, a library for reading, processing and writing MS Excel files, was used to create a MS Excel file and to output the results of database processing into it [14]. It has a huge set of powerful functions for creating and processing MS Excel files, therefore, with its help, working with files through the program code is almost the same as working in MS Excel.

According to the algorithms included in the program (Fig. 3, 4), the information from the database is divided into files of * .xlsx format, each of which contains information on the operating modes of the hot blast stoves block: the “on-gas” mode, the “on-blast” mode or the “on-switch” mode. The values of the dome and gas temperature in the checkerwork, as well as the hot blast temperature were chosen as the studied parameters characterizing the thermal state of the hot blast stove checkerwork.

After opening the program window (Fig. 5), the user needs to use the switch to select the type of databases for processing, and, if necessary, enter the tag numbers (except for the "wide" database) and select the step (interval) through which the data will be displayed.

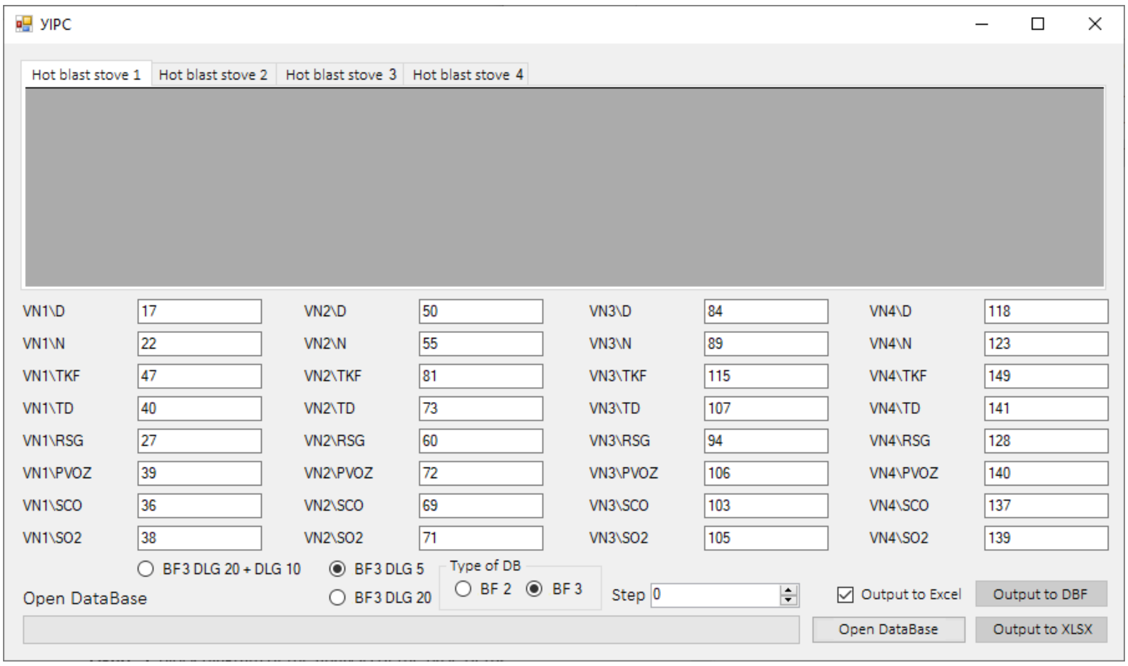


Figure 5: The main window of the program

After operation, the program for verification displays data for each hot blast stove in the appropriate tabs in the window (Fig. 6) and reports on the successful creation of Excel files with the results of calculations for each hot blast stove.

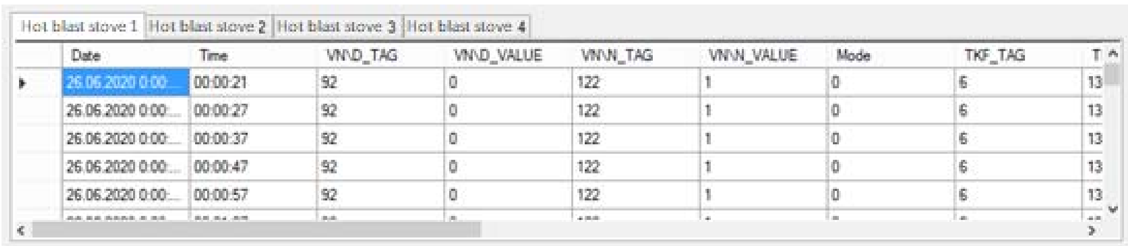


Figure 6: Data output for verification by tabs in the program subwindows

5. Research of the obtained results

5.1. Research of the change in the dome temperature during the "on-switch" mode of hot blast stoves

In the course of analyzing the database for a long period of operation of the hot blast stove block using the developed software, in addition to typical switchings (Fig. 7 a, b, 8 a, b), which correspond to the correct sequence of actions of the gas operator when switching operating modes, atypical switching were also found (Fig. 7 c, d, 8 c, d).

The graph of the dome temperature change for each switching (Fig. 7, 8) consists of three parts: in addition to the switching period, 50 values of the previous and subsequent modes are added.

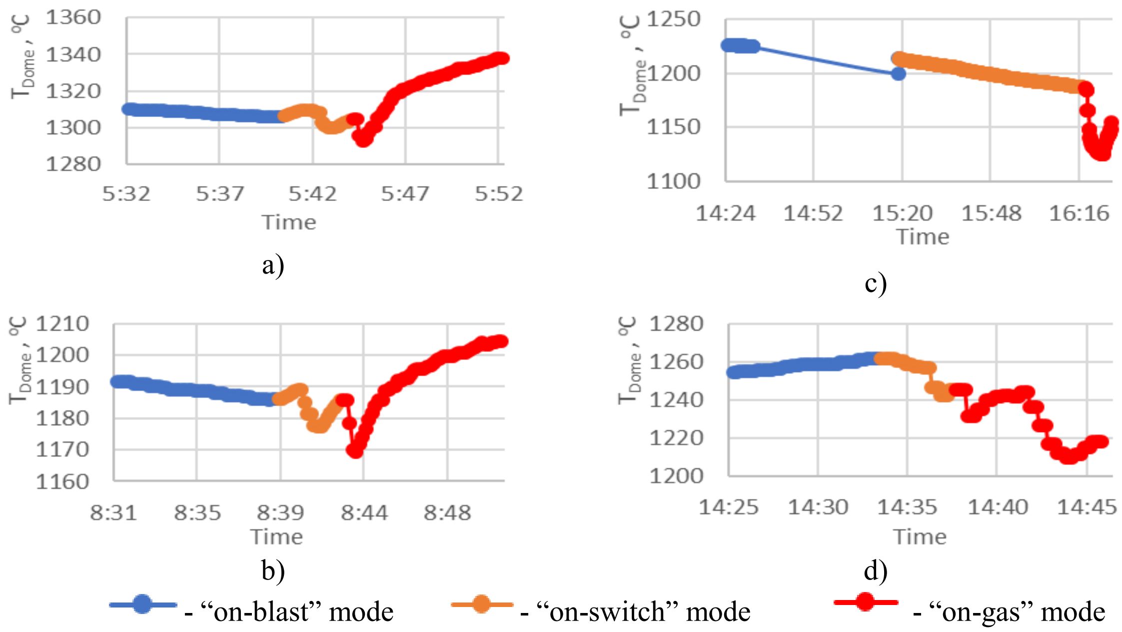


Figure 7: Switching of the hot blast stove from blast mode to heating mode

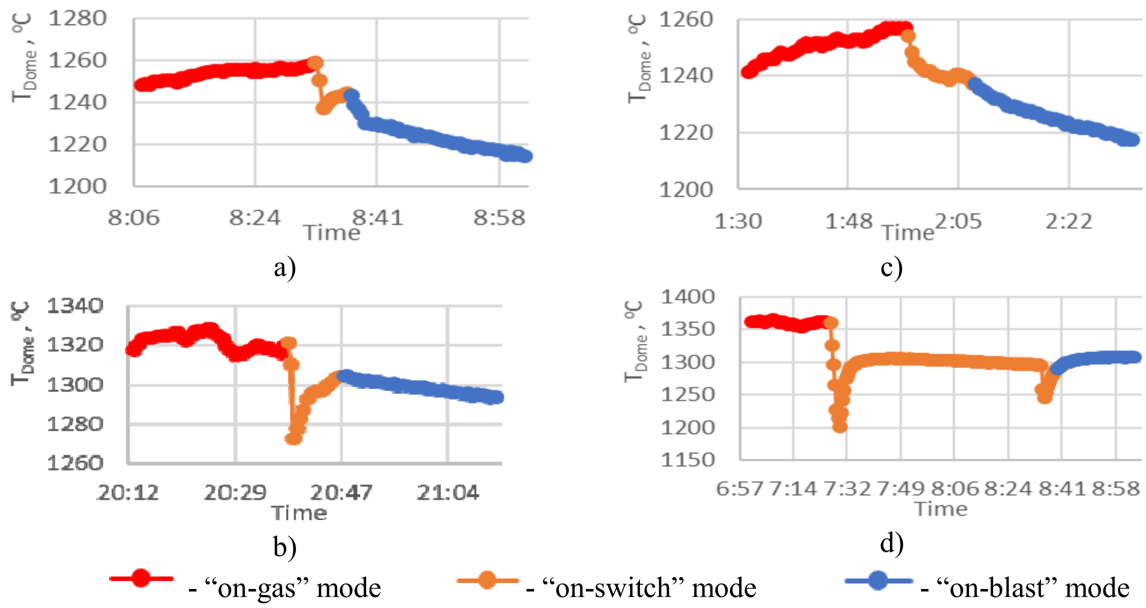


Figure 8: Switching of the hot blast stove from heating mode to blast mode

Typical switchings from the "on-gas" mode to the "on-blast" mode (Fig. 7 a, b) have a similar character, while lasting about 8-10 minutes, the dome temperature decreases by 15-25 °C;

Typical switching from the “on-blast” mode to the “on-gas” mode (Fig. 8 a, b) have the same character for all hot blast stoves, switching takes about 5 minutes, while the dome temperature drops by 15-20 °C.

During the “on-switch” mode, a drop in temperature can be observed within the range of 30-40 °C, and sometimes up to 50 °C, which must be taken into account when automatically controlling the subsequent operating mode of the hot blast stove.

5.2. Research of the “on-switch” mode of hot blast stoves of several different blocks

Using the developed program, the database has been studied over a long period to obtain and further analyze the averaged graphs of the temperature variation of the dome of hot blast stove of two blocks of different blast furnaces during the “on-switch” modes (Fig. 9).

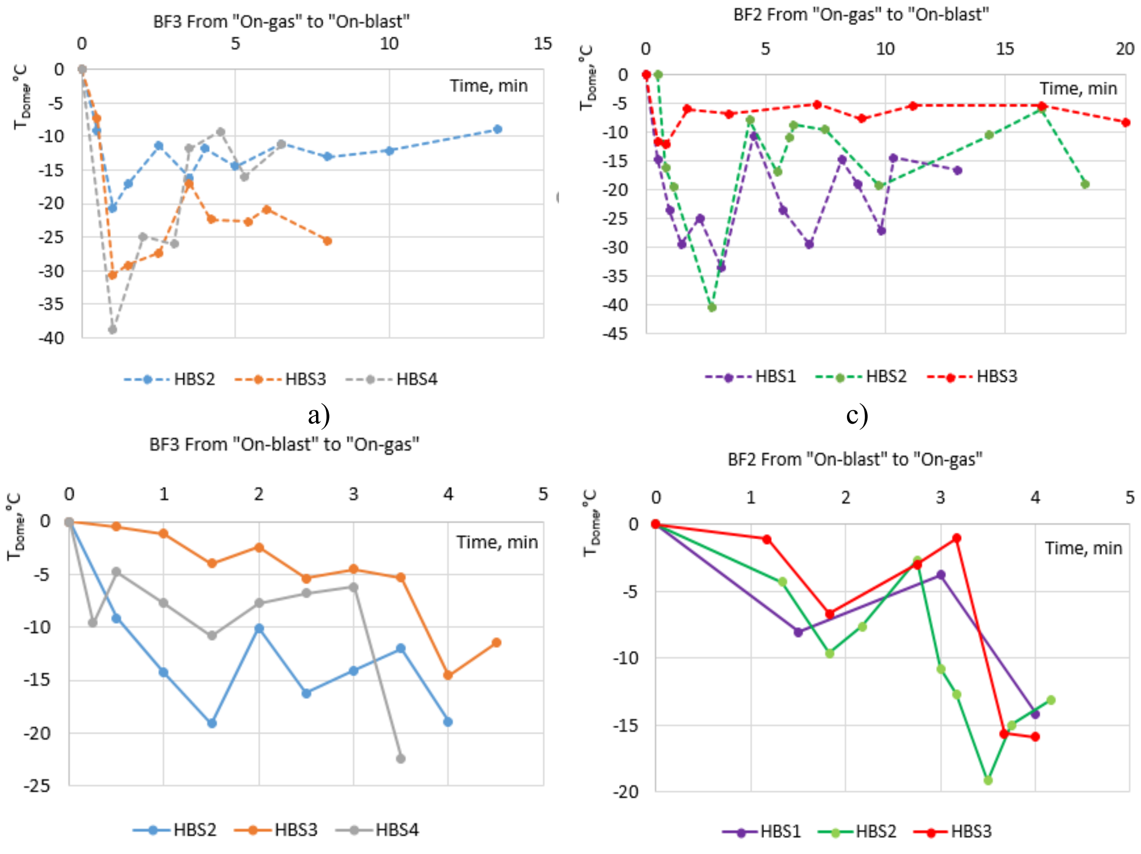


Figure 9: Average graphs of the dome temperature change during the “on-switch” mode

The change in the dome temperature during the “on-switch” mode from the “on-blast” to the “on-gas” modes has the same character and the duration of the “on-switch” mode corresponds to the parameter chart of operation of blocks adopted for the period under study (Fig. 9 b, d).

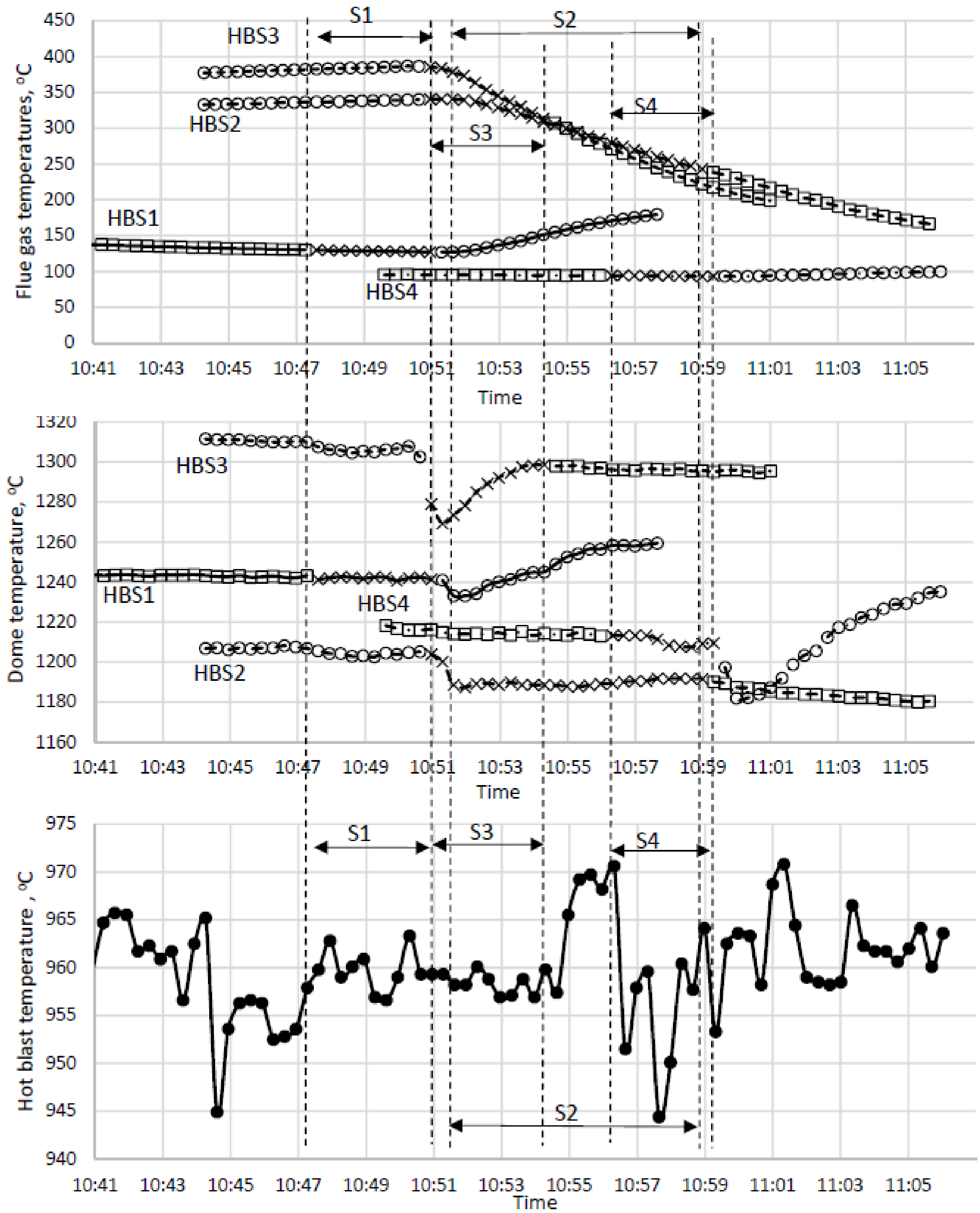
The duration of the “on-switch” mode from the “on-gas” to “on-blast” modes for HBS4 and HBS3 of the blast furnace No. 3 corresponds to the parameter chart, and for HBS it lasts twice as long as in the parameter chart.

The duration of the “on-switch” mode from the “on-gas” mode to the “on-blast” mode for all hot blast stoves of the blast furnace No. 2 is much longer, which is indicated in the parameter chart.

The obtained results must be taken into account in drawing up a new corrected parameter chart to optimize the operation of the hot blast stove block.

5.3. Impact of the "on-switch" on hot blast temperature

Of particular interest is a complex analysis of the "on-switch" modes of the block operating in parallel mode and their impact on the hot blast temperature (Fig. 10).



«On-gas»: - HBS1; - HBS2; - HBS3; - HBS4
«On-blast»: - HBS1; - HBS2; - HBS3; - HBS4
«On-switch»: - HBS1; - HBS2; - HBS3; - HBS4

S1 - switching HBS1 from "on-gas" to "on-blast", S2 - switching HBS2 from "on-gas" to "on-blast", S3 - switching HBS3 from "on-gas" to "on-blast", S4 - switching HBS4 from "on-blast" to "on-gas"

Figure 10: The impact of the "on-switch" of hot blast stoves on the temperature of the hot blast

Prior the "on-switch mode, the block of hot blast stoves was in parallel operation mode: HBS1 and HBS4 operated in the "on-gas" mode, HBS2 and HBS3 - in the "on-blast" mode.

Let us consider the "on-switch" mode sequence:

- - HBS1 was the first to switch to the "on-gas" mode - no blast temperature fluctuations were observed;
- then HBS2 and HBS3 began to switch to the "on-blast" mode - there is a sharp jump in the blast temperature by about 15 °C for 2 minutes;
- HBS4 was the last to switch to the "on-gas" mode - in this case, a sharp drop in the blast temperature by 25 °C is observed;
- after the end of the "on-switch" mode, the temperature of the hot blast stabilizes.

Stabilization of the blast temperature during the "on-switch" is one of the most important tasks of today, since fluctuations in the blast temperature negatively affect the course of blast furnace smelting [15], therefore, information on the nature of fluctuations in the hot blast temperature should be transmitted to the automatic control system.

5.4. Structure of Automated Process Control System on the Basis of the Proposed Algorithm

The authors propose a new structure of the automatic control system for the hot blast stoves block based on the data mining subsystem (Fig. 11), developed on the basis of information (dome and flue gas temperatures, hot blast temperatures, valve positions) obtained from the archive database, and the results of the performed research of the state of the hot blast stove during the "on-switch" mode.

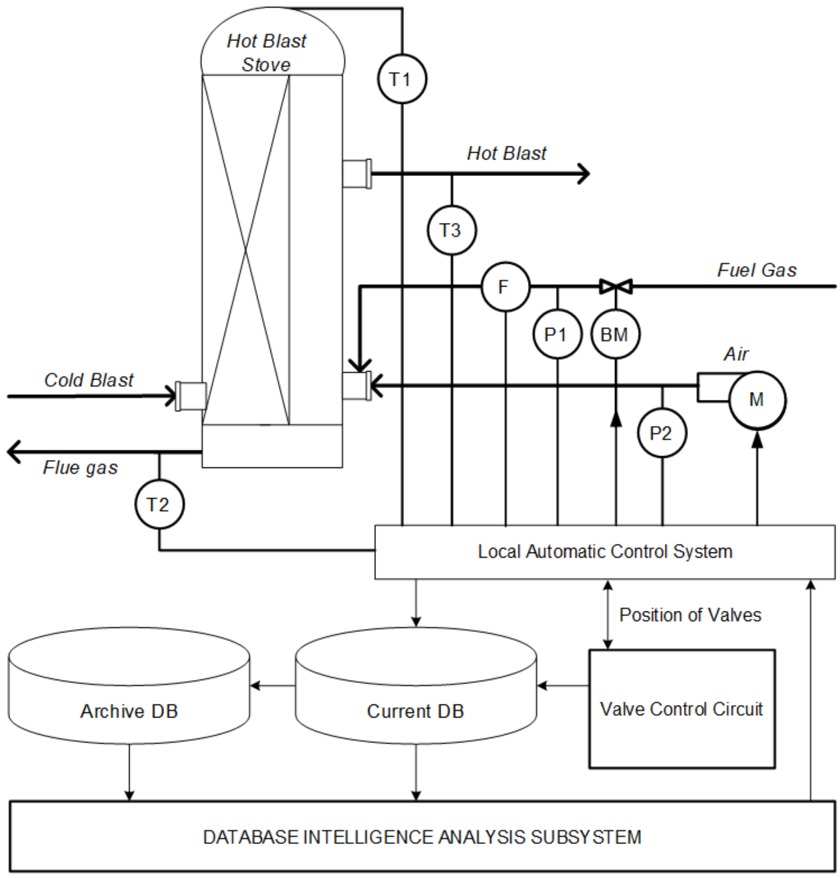


Figure 11: The structure of the hot blast stove checkerwork heating ACS based on the data mining subsystem

Current values of temperatures of the dome (T1), flue gases (T2) and hot blast (T3), flow rates (F) and mixed gas pressure (P1), combustion air pressure (P2), information on the position of valves from the valve control circuit are controlled in the local automatic control system (LACS) and are recorded in the current and archive database.

The data mining subsystem, based on the current technological information, monitors the change in the operating modes of the hot blast stoves, analyzes the state of the hot blast stoves during “on-switch”, compares with the archived information and makes adjustments to the operating modes of the hot blast stoves block.

If an increase in the duration of the hot blast stove switching to the “on-gas” mode is detected (a decrease in the dome temperature and an increase in heat losses to the environment, which leads to an increase in the duration of the “on-gas’ mode), the data mining subsystem will send corrections to the set mixed gas flow rate to the LACS system, which will ensure the achievement of the set heating duration of the checkerwork.

Subject to availability of a mathematical model of the operation of the hot blast stove [16] in the automatic control system of the block, based on the information on switching and data mining of the durations of the “on-gas” and the “on-blast” modes [17], it becomes possible to correct the parameter chart of the hot blast stoves block for the set period of time of operation of the hot blast stoves block.

The application of the proposed method of data mining of the current technological information about the heating of the hot blast is a new approach in the design of automatic control systems for the hot blast stoves block, which allows to maintain the set temperature of the hot blast without impressive capital costs for the reconstruction of the hot blast stoves block.

6. Conclusion

Data mining of the database containing current and archived information on the technological process of blast-furnace heating must be used in automatic control systems. The usage of the obtained results of the analysis of the “on-switch” mode of the hot blast stove will allow to make timely adjustments to the parameter chart of the hot blast stoves block, to clarify the initial values of modeling the operation of the hot blast stove.

The authors have developed an algorithm for data mining of technological information, which allows to assess the state of the hot blast stove during the periods of the “on-switch” mode. A software tool for automated processing of databases has been developed, which significantly accelerates the process of study of hot blast stoves and minimizes the risk of errors during processing.

The analysis of the change in the dome temperature and the smoke temperature during the “on-switch” mode of the hot blast stove and the effect of switching on the blast temperature has been performed.

The structure of an automatic control system for blast furnace heating using a data mining subsystem has been proposed.

Application of the proposed data mining algorithm in the automatic control system will allow to increase the hot blast temperature without significant capital investments in the reconstruction of the hot blast stoves block.

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